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Preconceptual Design Studies and Cost Data of Depleted Uranium Hexafluoride Conversion Plants

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Lawrence Livermore National Laboratory

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Prepared by
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Preface

One of the more important legacies left with the Department of Energy (DOE) after the privatization of the United States Enrichment Corporation is the large inventory of depleted uranium hexafluoride (DUF6). The DOE Office of Nuclear Energy, Science and Technology (NE) is responsible for the long-term management of some 700,000 metric tons of DUF6 stored at the sites of the two gaseous diffusion plants located at Paducah, Kentucky and Portsmouth, Ohio, and at the East Tennessee Technology Park in Oak Ridge, Tennessee. The DUF6 management program resides in NE's Office of Depleted Uranium Hexafluoride Management.

The current DUF6 program has largely focused on the ongoing maintenance of the cylinders containing DUF6. However, the long-term management and eventual disposition of DUF6 is the subject of a Programmatic Environmental Impact Statement (PEIS) and Public Law 105-204. The first step for future use or disposition is to convert the material, which requires construction and long-term operation of one or more conversion plants. To help inform the DUF6 program's planning activities, it was necessary to perform design and cost studies of likely DUF6 conversion plants at the preconceptual level, beyond the PEIS considerations but not as detailed as required for conceptual designs of actual plants.

This report contains the final results from such a preconceptual design study project. In this fast track, three month effort, Lawrence Livermore National Laboratory and Bechtel National Incorporated developed and evaluated seven different preconceptual design cases for a single plant. The preconceptual design, schedules, costs, and issues associated with specific DUF6 conversion approaches, operating periods, and ownership options were evaluated based on criteria established by DOE. The single-plant conversion options studied were similar to the dry-conversion process alternatives from the PEIS. For each of the seven cases considered, this report contains information on the conversion process, preconceptual plant description, rough capital and operating costs, and preliminary project schedule.

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The work was performed by the Fission Energy and Systems Safety Program at Lawrence Livermore National Laboratory (LLNL), and by Bechtel National Incorporated (Bechtel) as a subcontractor to LLNL. The preconceptual designs, cost estimates, and preliminary schedules were based on case options and criteria established by DOE/NE. Significant contributors, co-authors, or reviewers to this fast track, three month study included (in alphabetical order):

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Acronyms

AHF	Anhydrous hydrogen fluoride
CAF2	Calcium fluoride
D&D	Decontamination and Decommissioning
DOE	Department of Energy
DUF6/UF6	Depleted Uranium Hexafluoride
EIS	Environmental Impact Statement
GDP	Gaseous diffusion plant
GOCO	Government Owned and Contractor Operated facility
HF	Hydrogen fluoride
MT	Metric Tons
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Commission
O&M	Operations and Maintenance
PEIS	Programmatic Environmental Impact Statement
POPO	Privately owned and privately operated facility
SSC	Structures, systems, and components
UO2	Uranium dioxide
U3O8	Uranium oxide
USEC	United States Enrichment Corporation

1. Background to Preconceptual Design Studies of Conversion Plant Options

One of the more important legacies left with the Department of Energy (DOE) after the privatization of the United States Enrichment Corporation (USEC) is the large inventory of depleted uranium hexafluoride (DUF6). Some 700,000 metric tons (MT) of DUF6 are stored at the sites of the two gaseous diffusion plants located at Paducah, Kentucky and Portsmouth, Ohio, and at the East Tennessee Technology Park in Oak Ridge, Tennessee.

The current DUF6 management program has largely focused on the ongoing maintenance of the cylinders containing DUF6. The question, however, of the long-term management and eventual disposition of DUF6 is the subject of a Programmatic Environmental Impact Statement (PEIS) and considerable debate in Congress. Congress stated its intentions with regard to DUF6 in Public Law 105-204. This law directed the Secretary of Energy to prepare a plan to ensure that all funds accrued on the books of USEC for the disposition of DUF6 will be used for the construction and operation of plants to treat and recycle the DUF6 consistent with the National Environmental Policy Act (NEPA).

"Treat and recycle," in this context, refers to the chemical processing of DUF6 to remove the fluorine and create products that would present both a lower long-term storage hazard and provide material that would be suitable for use or disposal. Importantly, this would also allow the private and government sectors to explore the reuse of some of the end products resulting from the conversion of DUF6.

The first step for future use or disposition is to convert the material. To do so, construction and long-term operation of one or more conversion plants is essential. Traditionally, a project like this might be the subject of a multi-year Federal government-managed project to build one or two plants. However, such projects require a significant outlay of Federal funds early on and require many years to complete. In comparison, the private sector is well-equipped to pursue plant projects expeditiously and economically, as needed for the DUF6 program.

Thus, to help inform the program's planning activities, it is essential to perform design and cost studies, at least at the preconceptual level, of likely DUF6 conversion plants, whether they are government owned and contractor operated or privately owned and operated. This requires evaluations of conversion capability specifics and costs beyond the PEIS considerations, but not as detailed as required for conceptual designs of actual plants. This report contains results from such a preconceptual design study project.

2. Overview of Preconceptual Design Study Project

2.1 Introduction/Methodology

The PEIS (*Programmatic Environmental Impact Statement for Alternative Strategies for the Long-Term Management and Use of Depleted Uranium Hexafluoride)* considers alternatives for the long-term management of the DUF6 stockpile. Engineering analyses and cost analyses for each of the alternatives were also prepared to support the PEIS. The projected costs of the alternatives were developed in the *Cost Analysis Report for the Long-Term Management of Depleted Uranium Hexafluoride* (Cost Analysis Report). The engineering and cost analyses used generic basis assumptions to be applied to the evaluation of all alternatives. In this sense, these previous studies were 'parametric' and did not address site-specific and technology-specific issues. For instance, the cost analysis was intended to identify the relative differences in costs for purposes of making comparisons and do not provide absolute costs for developing project budgets or procurement documents. Furthermore, the estimates in the Cost Analysis Report do not represent costs "to" any particular entity, either public or private.

This project seeks to improve the situation by evaluating the preconceptual design, costs, schedule, and issues associated with specific DUF6 conversion technologies. The scope of the preconceptual design study, see Figure 2.1, is focused on the conversion module of the DUF6 management strategy. It is a single plant study, with different conversion options considered. The other elements of an integrated management strategy are not included in this study, such as management of the DUF6 storage containers, transportation to and from the conversion plant, nor use, long-term storage, or disposition options. However, potential expanded interim storage of conversion product at the conversion plant is part of the study scope.

The single-plant conversion options studied were based on the conversion alternatives from the PEIS. DOE selected the cases of most interest to them, see Section 2.2. The studies focused on the preconceptual life-cycle costs, schedule, and other issues pertinent to the early construction of conversion facilities. The DOE plan is based on an aggressive schedule to begin construction of conversion facilities in 2002, and relies on significant private sector involvement to be successful.

The conversion and operation of the conversion plant is based on one of two basic scenarios: the plant will be government-owned and contractor operated in conformance with DOE standards (GOCO), or the plant will be under private ownership and operation with DOE regulations (POPO). In addition, case options were developed for both 25-year and 15-year operations. The 25-year operation is consistent with the PEIS considerations. The 15-year operation was chosen as a potential alternative for earlier recovery of capital, siting, financing, and return on investment to the private sector.

More detailed information on the design bases and assumptions employed in this study are contained in Section 2.3 and Sections 4 through 7.

This was a fast track study: seven conversion options were analyzed in a period of three calendar months. As such, the studies utilized already available information from a variety of sources like reports and literature, personal communications and quotes, estimates for similar equipment, current estimating manuals, and in-house databases.

This report is organized in the following manner. Sections 2 and 3 provide summary information and results, respectively, based on all the case studies performed. Sections 4-7 each corresponds to the preconceptual study for one of the four major conversion cases. Each of these sections is written to be a stand-alone report, in case parties are only interested in specific conversion plants. This results, however, in some redundancy of information among the major sections of the report.

2.2 Summary of Cases Considered

In order to examine the costs and issues involved in a 2002 time frame for construction start, DOE selected four plant conversion cases:

- A conversion plant using a dry process to convert DUF6 to uranium oxide (U3O8) and anhydrous hydrogen fluoride (AHF) as final products.

- A conversion plant using a dry process to convert DUF6 to uranium oxide (U3O8) and anhydrous hydrogen fluoride (AHF) and calcium fluoride (CaF2) as final products.

- A conversion plant using a dry process to convert DUF6 to uranium dioxide (UO2) aggregate and anhydrous hydrogen fluoride (AHF) as final products.

- A conversion plant using a dry process to convert DUF6 to uranium oxide (U3O8) and calcium fluoride (CaF2) as final products.

The last case, U3O8/CaF2, was used for a preliminary preconceptual study which helped to establish a protocol for the other studies. The U3O8/AHF became the base study, with the most options considered, for this project.

A process block flow diagram of the base case conversion is provided in Figure 2.2 to illustrate the elements incorporated in the conversion facility considerations.

All cases entailed a preconceptual plant design, rough cost estimate, and preliminary project schedule. The conversion plant includes capabilities for DUF6 cylinder preparation, conversion of DUF6 to uranium oxide and fluorine byproducts, empty cylinder treatment for disposal, and interim storage for oxide and byproducts.

2.2.1 DUF6 Conversion to U3O8/AHF

This base case study is a conversion plant using a dry process to convert DUF6 to uranium oxide (U3O8) and anhydrous hydrogen fluoride (AHF) as final products. The construction and operation of the U3O8/AHF conversion plant depends on one of two basic scenarios: GOCO or POPO. In addition, case options were developed for both 25-year operations and 15-year operations, which gives a total of four options.

Depleted uranium hexafluoride (DUF6) is processed to produce U3O8 and AHF. For 25-year operation, the average throughput is 5.1 cylinders per day (5,670 lb/hr UF6). For 15-year operation the average throughput is 8.5 cylinders per day (9,450 lb/hr UF6). These figures are based on 80% plant availability (7,000 hours/yr or 292 days/yr).

The DUF6 gas is converted to U3O8 in a series of two reaction chambers, where it is mixed with an HF/water vapor mixture in the first reaction chamber and with steam in the second reaction chamber. The chemical reactions are:

$$UF6 + 2\ H_2O \dashrightarrow UO2F_2 + 4\ HF$$

$3\ UO2F_2 + 3\ H_2O$ ---> U3O8 + 6 HF + 0.5 O_2

For 25-year operation, four reaction lines are provided to meet the required throughput. (Six lines are provided in the 15-year scenario). The U3O8 product is cooled, compacted to increase its bulk density, and packaged in metal bins. The filled bins are transferred to the U3O8 Storage Building.

Reaction chamber off-gas containing HF, steam and oxygen is filtered to remove uranium particulates. The off-gas then flows to one of two HF distillation systems, which concentrates the mixture to produce anhydrous HF in the overhead product. The AHF is collected, sampled, and pumped to large storage tanks in the HF Storage Building, where the AHF is loaded into railcars or tank trucks for delivery to customers. The AHF is expected to contain less than 1 ppm uranium.

2.2.2 DUF6 Conversion to U3O8/AHF/CaF2

This plant construction is based on a conversion plant using a dry process to convert DUF6 to uranium oxide (U3O8), anhydrous hydrogen fluoride (AHF) and calcium fluoride (CaF2) as final products. The plant has two operating modes: 100% production of AHF only or 100% production of only CaF2 . The construction and operation of the conversion plant is based on private ownership and operation with DOE regulations and operating for 25 years.

Depleted uranium hexafluoride (DUF6) is processed to produce U3O8, AHF and CaF2. The average throughput is 5 cylinders per day (5,670 lb/hr DUF6) based on 80% plant availability (7,000 hours/yr or 292 days/yr).

The plant is designed to produce AHF or CaF2, but not both simultaneously. Production would be shut down during the transition between the AHF and CaF2 production modes. The desired mix of AHF and CaF2 product is obtained by campaigning operations. Much of the equipment is common and would be used during both production modes.

The AHF production mode is as in Section 2.2.1 above.

For the calcium fluoride production mode, the DUF6 gas is converted to U3O8 in a series of two reaction chambers, where it is mixed with steam and nitrogen in the first chamber and steam and hydrogen in the second chamber. The chemical reactions are:

UF6 + 2 H_2O ---> $UO2F_2$ + 4 HF

$3\ UO2F_2 + 3\ H_2O$ ---> U3O8 + 6 HF + 0.5 O_2

$H_2 + 0.5\ O_2$ ---> H_2O

The U3O8 product is cooled, compacted to increase its bulk density, packaged in metal bins, and transferred to the U3O8 Storage Building. Reaction chamber off-gas containing HF, excess steam, and nitrogen is filtered to remove uranium particulates. The reaction chambers, filters and U3O8 handling equipment are the same ones used in the AHF production mode.

After filtration, the reaction off-gas flows to the HF absorption columns, where the HF and steam are contacted with a liquid solution and condensed. The aqueous HF solution that is produced from absorption is transferred to neutralization tanks and neutralized with slaked lime according to the reaction:

2 HF + $Ca(OH)_2$ ---> CaF2 + 2 H_2O

The resulting CaF2 precipitate is separated by filtering, washed with water, dried and loaded into bins. The CaF2 is expected to contain less than 1 ppm uranium.

2.2.3 DUF6 Conversion to UO2/AHF

This case study examines the cost and issues for plant construction based on a conversion plant using a dry process to convert DUF6 to uranium dioxide aggregate and anhydrous hydrogen fluoride (AHF) as final products. The UO2 aggregate can be used to make dense concrete for shielding applications. The construction and operation of the conversion plant is based on private ownership with DOE regulations and operating for 25 years.

Depleted uranium hexafluoride (DUF6) is processed to produce UO2 aggregate and AHF. The average throughput is 5 cylinders per day (5,670 lb/hr DUF6) based on 80% plant availability (7,000 hours/yr or 292 days/yr).

The DUF6 gas is converted to UO2 in a series of two reaction chambers, where it is mixed with an HF/water vapor mixture in the first reaction chamber and with steam, nitrogen and hydrogen in the second reaction chamber. The chemical reactions are:

$UF6 + 2\ H_2O \text{ ---> } UO2F_2 + 4\ HF$

$UO2F_2 + H_2 \text{ ---> } UO2 + 2\ HF$

Four reaction lines are provided to meet the required throughput. The UO2 product is cooled and conveyed to indoor silos for interim storage.

The UO2 is mixed with additives, milled and pressed into pellets. The pellets are sintered to form dense ceramic pellets and packaged in boxes. The filled boxes are transferred to the UO2 storage building.

Reaction chamber off-gas containing HF, steam, nitrogen and hydrogen is filtered to remove uranium particulates. The off-gas then flows to an HF distillation system, which concentrates the mixture to produce anhydrous HF in the overhead product. The AHF is collected, sampled, and pumped to large storage tanks in the HF Storage Building, where the AHF is loaded into railcars or tank trucks for delivery to customers. The AHF is expected to contain less than 1 ppm uranium.

2.2.4 DUF6 Conversion to U3O8/CaF2

For this preconceptual design project, the preliminary case study was based on a conversion plant using a dry process to convert DUF6 to uranium oxide (U3O8) and calcium fluoride (CaF2) as final products. The process selected to study involves least process equipment and byproduct streams. The construction and operation of the conversion plant is based on a government owned and contractor operated facility in conformance with DOE standards and operating for 25 years.

Depleted uranium hexafluoride (DUF6) is processed to produce uranium oxide (U3O8) and calcium fluoride (CaF2). The average throughput is 5 cylinders per day (5,670 lb/hr DUF6) based on 80% plant availability (7,000 hours/yr or 292 days/yr).

The DUF6 gas is mixed with steam, nitrogen and hydrogen and converted to U3O8 in a series of two reaction chambers. The chemical reactions are:

$UF6 + 2\ H_2O \text{ ---> } UO2F_2 + 4\ HF$

$3\ UO2F_2 + 3\ H_2O \longrightarrow U3O8 + 6\ HF + 0.5\ O_2$

$H_2 + 0.5\ O_2 \longrightarrow H_2O$

Four reaction lines are provided to meet the required throughput. The U3O8 product is cooled, compacted with a rotary compactor to increase its bulk density, and packaged in metal bins. The filled bins are transferred to the U3O8 Storage Building.

Reaction chamber off-gas containing HF, excess steam, and nitrogen is filtered to remove uranium particulates. The off-gas flows to the HF absorption columns, where the HF and steam are condensed and an aqueous HF solution is produced. The HF solution is neutralized with slaked lime according to the reaction:

$2\ HF + Ca(OH)_2 \longrightarrow CaF2 + 2\ H_2O$

The resulting CaF2 precipitate is separated by filtering, washed with water, dried and loaded into bins and are transferred to the CaF2 Storage Building. The CaF2 is expected to contain less than 1 ppm uranium.

2.3 Design Basis and Assumptions

This section summarizes the major design bases and assumptions impacting the results of the preconceptual design, cost estimates, and scheduling. Detailed bases and assumptions are contained in Sections 4-7 for each study option.

Significant design bases for the conversion plants include:

- The plants will convert DUF6 by a dry process.
- The plant capacity will be designed to process a DUF6 inventory of 36,910 cylinders (450,000 MT DUF6) over the life of the plant (about 64% of the DOE inventory of 700,000 MT).
- Storage will be provided for one year production of uranium oxide and calcium fluoride products and two months production of AHF.
- The AHF product is sold by the DOE (GOCO) or plant owner (POPO) (depending on the case options) to commercial users. The U3O8 and CaF2 products are retained by the DOE, if the plant is government owned, or returned to the DOE, if the plant is privately owned.
- To bound costs associated with empty cylinders, assume all empty cylinders will be washed, compacted, and returned to the DOE for disposal.
- The plant will be located at a DOE owned site at or near a gaseous diffusion plant and include the support facilities and infrastructures/utilities needed for a greenfield facility.
- The design will consider addition of future process and storage buildings.

The Conversion Facility is assumed to be constructed on a DOE site at a greenfield, constructable location at or near a gaseous diffusion plant. The Conversion Facility includes full and empty cylinder storage pads, the Process Building, a U3O8 Storage Building, an HF Storage Building , a CaF2 Storage Building, a Waste Storage Building and support facilities. The site plan should consider the addition of future process facilities such as uranium metal.

The Conversion Facility will be designed and constructed in compliance with DOE Orders and applicable regulations and codes, and will meet the intent of NRC standards. In general, a graded approach as established in DOE Order 420.1 is used for the design of all structures, systems, and components (SSC) in the plant facilities. All SSC's will be assigned a Natural Phenomena Performance Category using the criteria in the DOE Standards DOE-STD-1020-94 and DOE-STD-1021-93 during the design phase. The more stringent requirements of the gaseous diffusion plant sites are used in this study.

The cost estimates are rough order of magnitude estimates based on a preconceptual level design information. The estimates include facility capital, O&M, D&D, and NEPA/Licensing costs. The estimates do not include costs for plant design criteria development, cost of land, site qualifications, or extension of local roads and utility lines to the site boundary. The estimates take into account the procurement pricing, labor productivity, and indirect cost factors for a government or private project. Detailed cost estimate bases are described in the Appendices.

Figure 2.3 summarizes the differences in cost factors used between the POPO and GOCO cases.

For the POPO cases, the assumed guaranteed maximum feed rate per annum is the total quantity of DUF6 (450,000 MT) divided by the product of the total number of years assumed to process this quantity and the plant availability factor. The guaranteed minimum feed rate per annum is 95% of the guaranteed maximum feed rate. It is also assumed there is no government financing, i.e., private financing only.

Private finance is used to raise the construction capital. The private finance is based on a construction loan with an assumed commercial interest rate to cover the design, construction, and startup expenditures. The loan is paid back during an assumed period after production start with operation revenues from conversion service payment and HF chemical sales.

The private operator will receive payment from the government for the conversion service. The payment is based on amount of DUF6 processed after production start at assumed rates such that the private operator's income is near break-even.

The DOE plan is based on an aggressive schedule to begin construction of conversion facilities in 2002. Thus, the schedule is based on a fast track premise with overlapping engineering phases and early procurement of some key equipment (most equipment is available in 12-18 month lead time) and a two-phase construction plan. The reader is advised to consider these schedules illustrative, rather than definitive. There are large uncertainties in the timing or delays in the DOE regulatory processes leading from selection of contractor to full operations.

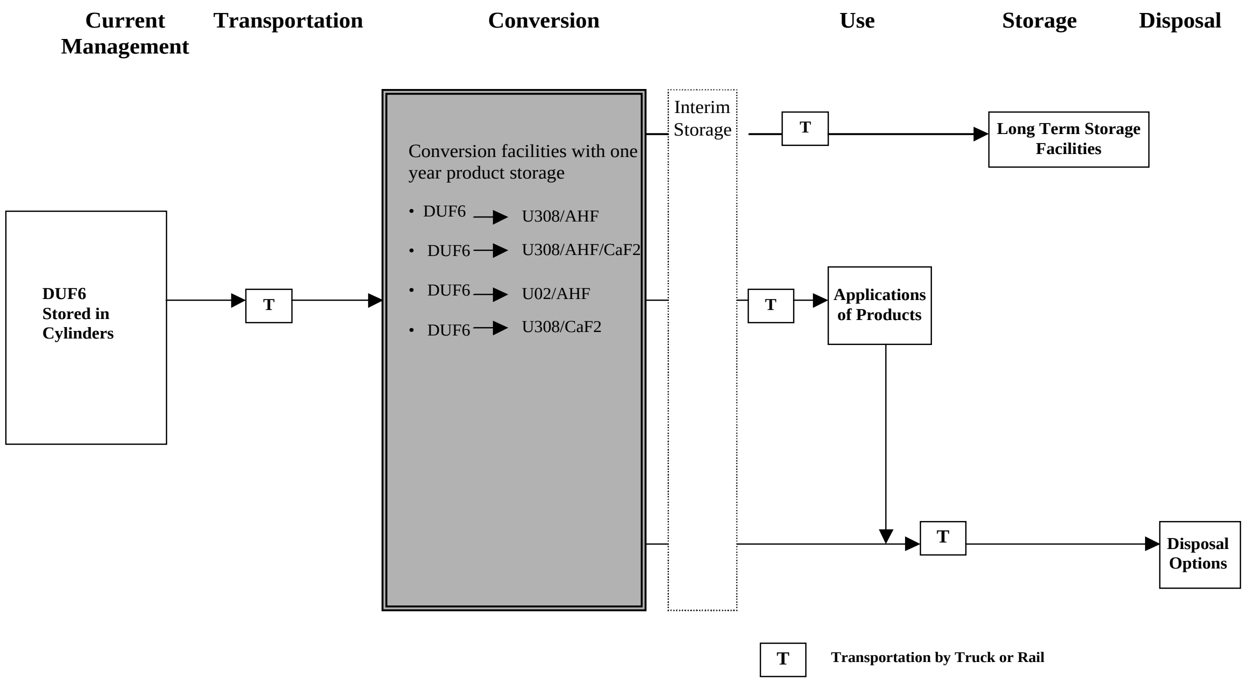


Figure 2.1 Scope of Study

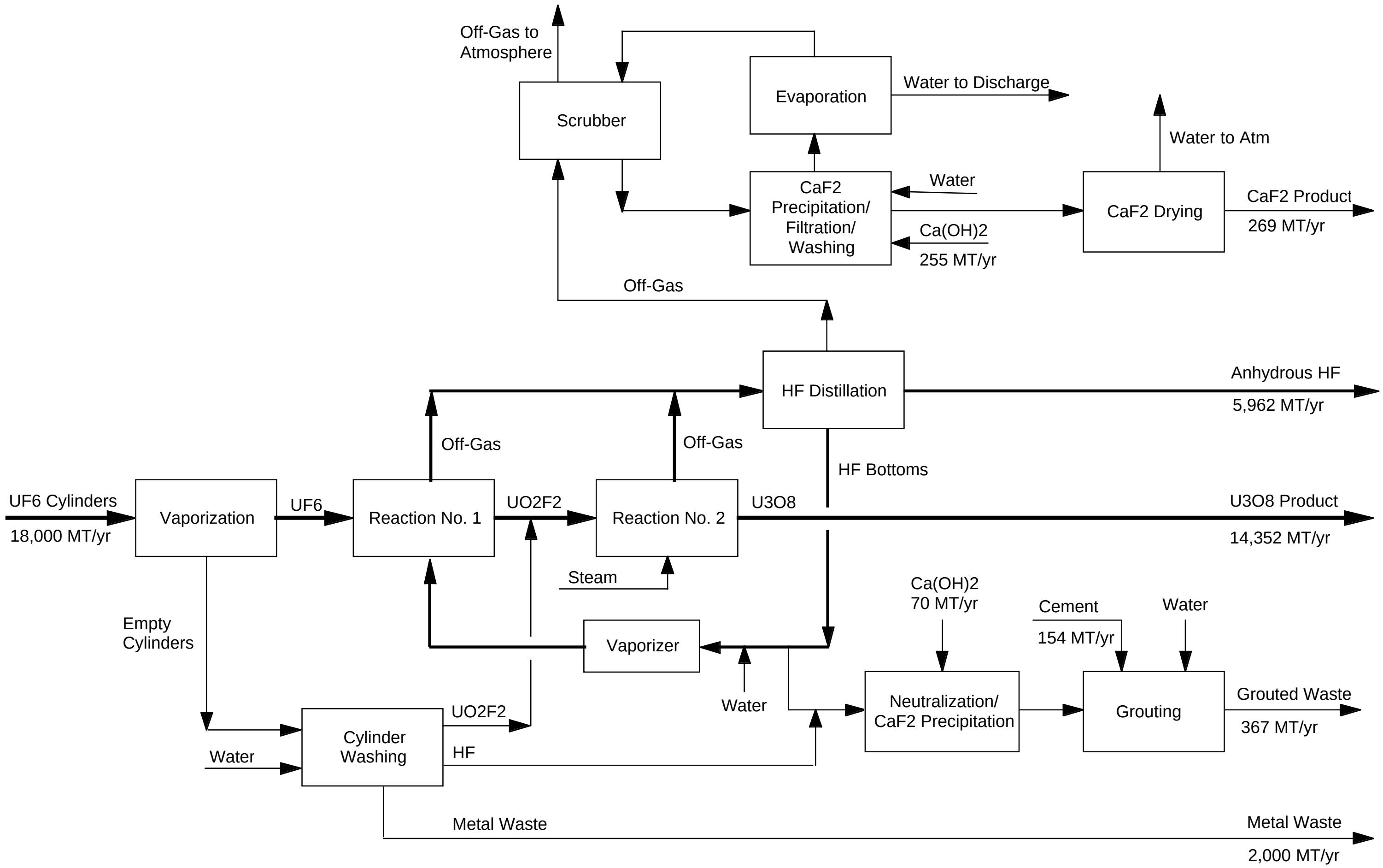


Figure 2.2 Process Block Flow Diagram Conversion to U3O8 and AHF

Capital Costs	
Wages	Same for POPO and GOCO
Materials	5% less for POPO
Productivity	5% greater for POPO
Engineering (% capital costs)	14.4% of capital costs for POPO 18% of capital cost for GOCO
Construction indirects	3% to 4% less for POPO
Operating and Maintenance Costs	
Wages	Same for POPO and GOCO
Indirects	2% less for POPO
Labor	Increased security and administrative for GOCO

Figure 2.3 Cost Estimate Factors for POPO vs. GOCO

3. Summary Results

This section contains illustrative results chosen to reflect the general outcomes of this study. More detailed and specific results for each case study can be found in Sections
4-7.

3.1 Overall Description of Facilities

Based on the preconceptual design considerations, a typical conversion facility conceptual site plan is shown in Figure 3.1. The Conversion Facility includes full and empty storage pads, the Process Building, a U3O8 Storage Building, a HF Storage Building, a CaF2 Storage Building, a Waste Storage Building and support facilities. The site plan shows addition of future process facilities.

A Process Building general arrangement for the base case U3O8/AHF conversion is provided in Figure 3.2 to illustrate the elements and their relationships incorporated in the conversion facility considerations. The arrangement maps to the process block flow diagram in Figure 2.2.

Some preconceptual facility design parameters are compared for the four conversion options in Table 3.1. This table also includes for comparison the 15-year operations for the base case U3O8/AHF conversion. In the 25-year operations all conversion plants process about 5 cylinders/day or 18,000 MT/yr of DUF6. In the 15-year configuration these numbers jump to 8.5 cylinders/day and to 30,000 MT/yr. The uranium product rate is approximately 14,500 MT/yr for all the conversion processes when scaled for 25-year operations. The productivity is 20% higher when scaled for 15-year operations. The AHF product is about 6,000 MT/yr for all conversion processes at 25-year operations, and increases by two-thirds for the 15-year option. The number of plant employees ranges from 179 to 218, depending on the conversion option and plant capacity.

3.2 Cost Estimates

The rolled-up costs (in FY 2000 dollars) for every preconceptual study case are provided and compared in Table 3.2. The life-cycle funding outlays for the various case options are summarized in the bottom line of Table 3.2. Note that byproduct sale revenue and construction loan interest are included. In the POPO cases, the total outlay is a break-even government payment that doesn't include profit, taxes and depreciation. In addition to a 10-year payback time for the POPO cases, the expenditure outlays for a 5-year payback time were developed for the U3O8/AHF base cases. The break-even payment for 5-year payback in the 15-year POPO case is $738M as opposed to $827M for a 10-year payback; and $779M as opposed to $845M in the 25-year POPO case.

The cost estimates vary depending on the scenario under discussion, and differ depending on whether the plant is government owned and contractor operated or privately owned and operated. The major contributors to the capital cost are the Process Building including the structure and service systems. Capital cost is very roughly 25% for process equipment, 25% process building, 25% product storage buildings and 25% site improvements and support facilities. The process equipment cost is roughly 30% cylinder handling and vaporization, 50% conversion to oxide, 15% AHF distillation and 5% miscellaneous. Roughly 2/3 of the annual O&M cost is labor cost. The cost to dispose of empty cylinder metal is not included in this report. If it is disposed as LLW, the disposal cost could be significant.

The annual expenditures required to support the construction and operation of the conversion plants were also developed. The expenditure profiles are derived from loading the estimated capital and operating costs onto the project schedule. A constant FY2000 dollar value is used in the expenditure outlay, because of the difficulty in accurately predicting the inflation rate for future years. An illustrative funding profile comparison for GOCO versus POPO for the 15-year U3O8/AHF conversion facility is presented graphically in Figure 3.3.

For the funding distributions of Figure 3.3, the POPO case accumulates debt in years 0-5 (at an assumed rate of 8.5%) and there is no financing (interest) cost for GOCO. The assumed loan payback period is 10 years, and it begins at plant operation start. Revenue from AHF sales is also assumed. All funding profiles are based on break-even cost/expenditure, i.e., there is no profit included in the POPO outlay. Figure 3.4 shows funding distributions with a 5-year loan payback period.

The government expenditure in the POPO case is minimal during the first five years and is steady at approximately $74 M/yr for years 5-15. This constant outlay reduces to approximately $21 M/yr between 15 and 20 years. The government outlay increases from $3M to $120M per year in the first five years, and then is steady at about $20M/yr from 5 to 20 years. Note that, even though the government outlay in the first five years of POPO is minimal, the total break-even outlay is greater for POPO than for GOCO by approximately $170M over the plant lifetime. However, if a 5-year payback is used, the total POPO outlay exceeds the GOCO outlay by $80M over the plant lifetime.

3.3 Schedules

Estimated preliminary project schedules were developed for each conversion plant option. The schedules are based on a fast track premise, with overlapping engineering phases, early procurements, and a construction plan, in order to meet the desired objective of construction start in year 2002. A simplified schedule for the initial years of the project for GOCO 25-year operations is shown in Figure 3.5.

The 2002 construction start depends on the key milestone dates for site selection, selection of primary contractor and construction contractor, and construction approval. The schedule includes NEPA activities, as a site-specific EIS will be required, as well as DOE regulatory activities. The schedules show late 2001 to early 2002 construction start and 2004 start-up (the 15-year operation plant requires an additional six months before start-up in both the POPO and GOCO cases). This appears to be attainable if the key procurement, engineering, and construction approval milestones are met. The schedule differences between POPO and GOCO – on the order of six months longer for POPO – is probably not significant but strongly depends on the decision making process. There are large uncertainties in the timing or delays in the DOE regulatory processes leading to full operations.

3.4 U3O8 Storage Issue

A primary issue identified during this project was that the amount of U3O8 storage provided affects cost and probably needs additional study to find less expensive storage modalities. The U3O8 storage design used in this preconceptual study is large and expensive for each year of storage capacity. It might be considered an upper bound on uranium oxide storage design.

A one-year capacity U3O8 storage building holds 1760, 4x4x7 foot high, bins stacked one high. Bins were used to package the U3O8 because of the space savings compared to 55-gallon drums. With no stacking, the U3O8 Storage building is 240 ft x 350 ft x 15 ft high or 84,000 sq. ft. A general storage arrangement in the U3O8 building is shown in Figure 4.4. The cost per storage building is estimated at $23M (25 year case) and $29M (15 year case) including engineering. Additional storage capacity would require about 5 acres (site improvements and utilities) for each year of additional U3O8 storage.

The U3O8 storage buildings are assumed PC-2 to maintain storage function after the occurrence of a natural phenomena hazards event. These buildings are steel frame and concrete clad panel construction and are ventilated and lighted, but no heating, cooling or HEPA filtration is provided. Access aisles allow personnel to inspect the bins during storage.

Additional study is needed to determine the most cost effective storage method, including the best storage container to use with the cost considerations on facilities and transport.

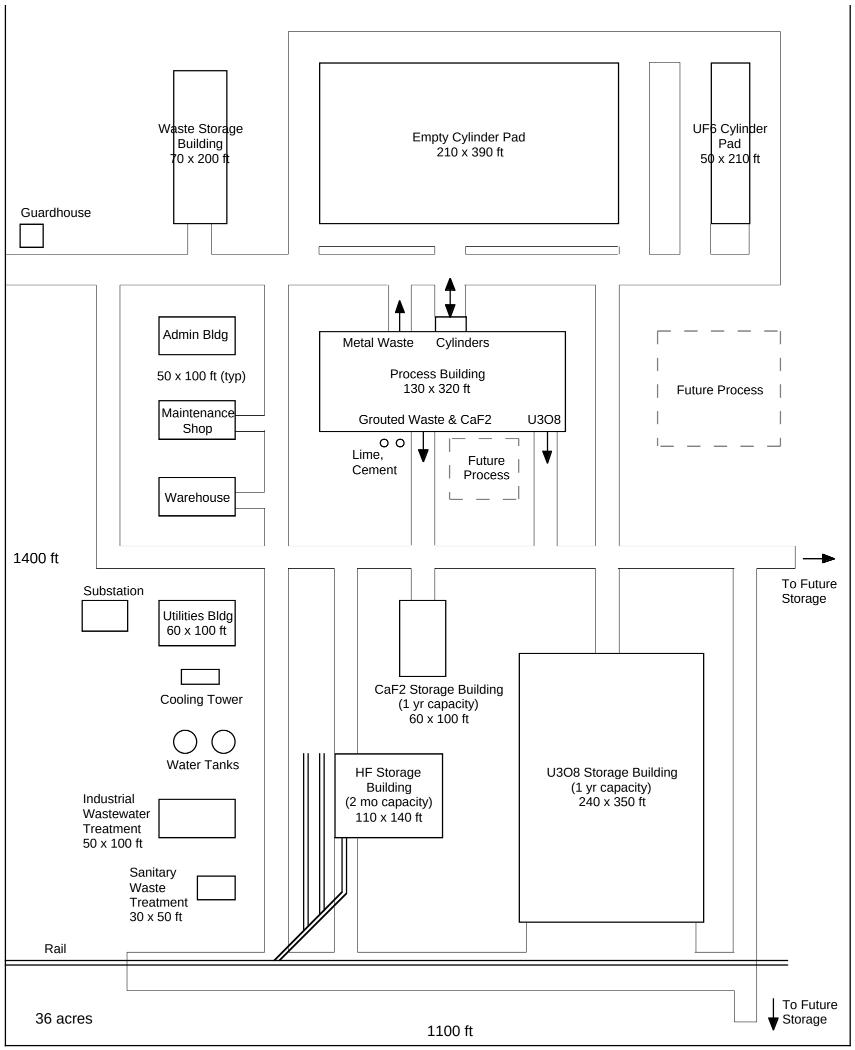


Figure 3.1 Conversion Facility and Storage Site Plan DUF6 Conversion to U3O8 and AHF

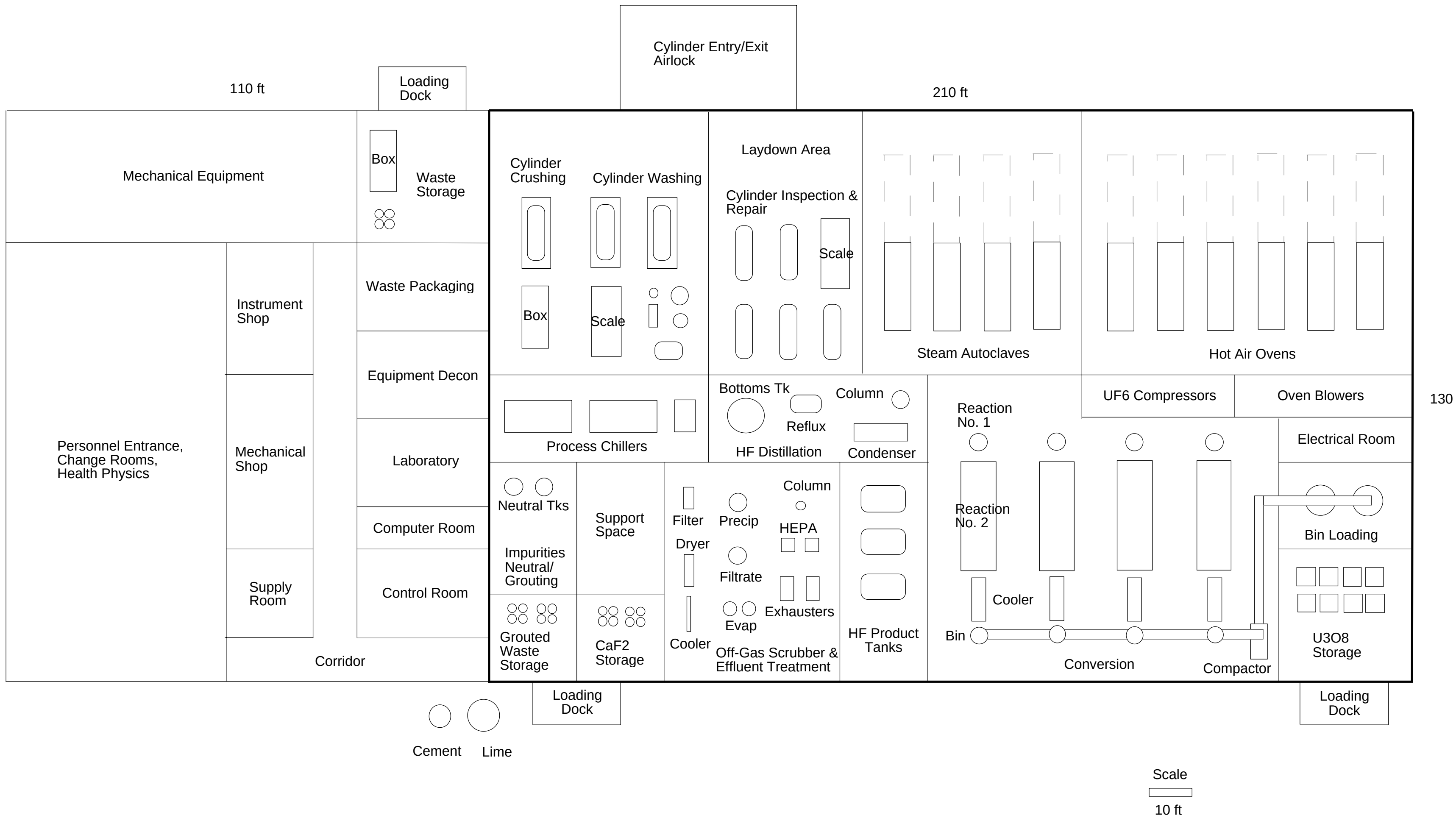


Figure 3.2 Process Building General Arrangement Conversion to U3O8 and AHF

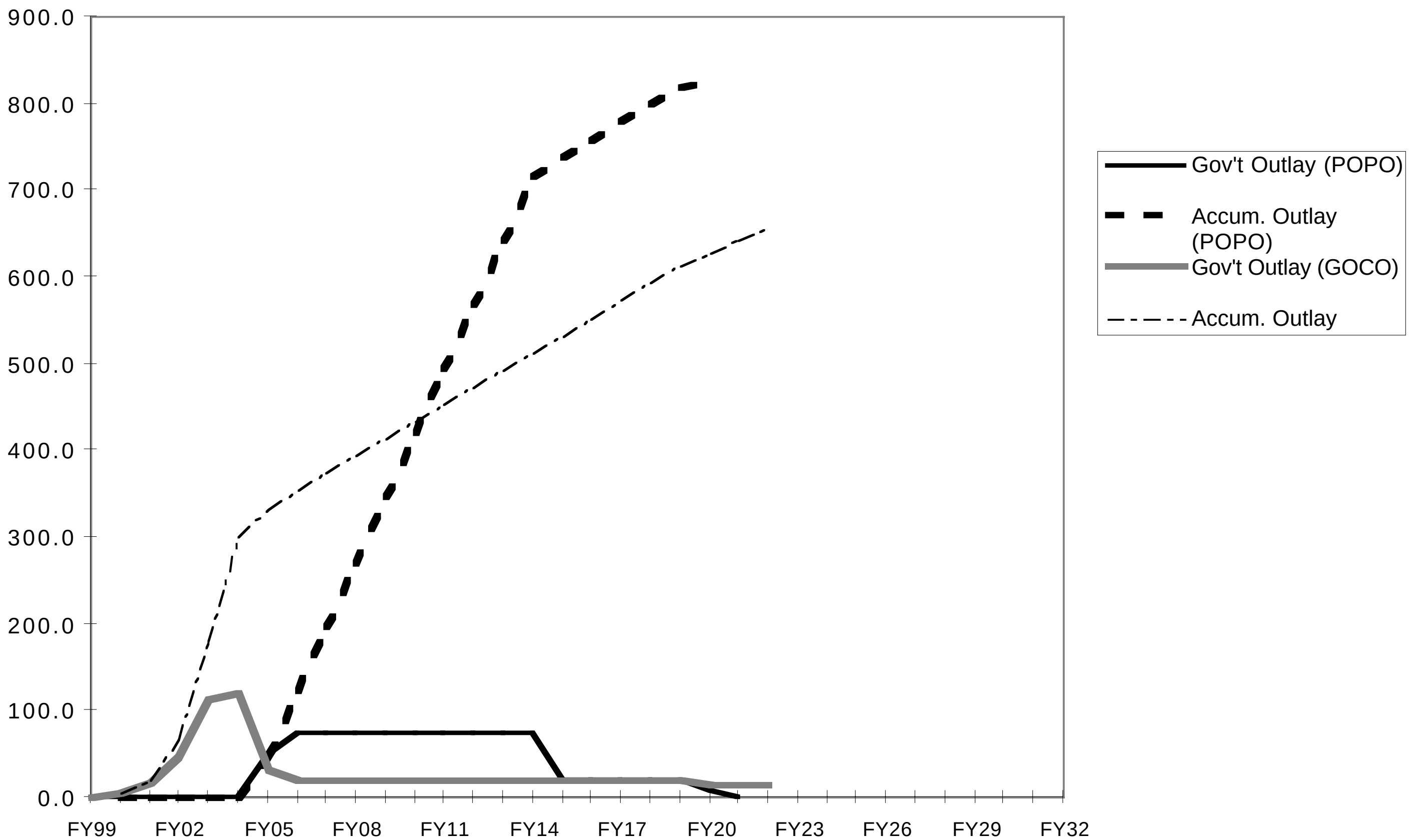


Figure 3.3 Funding Profiles GOCO vs. POPO – 15 Years U3O8/AHF
(w/10 year loan payback time in POPO case)

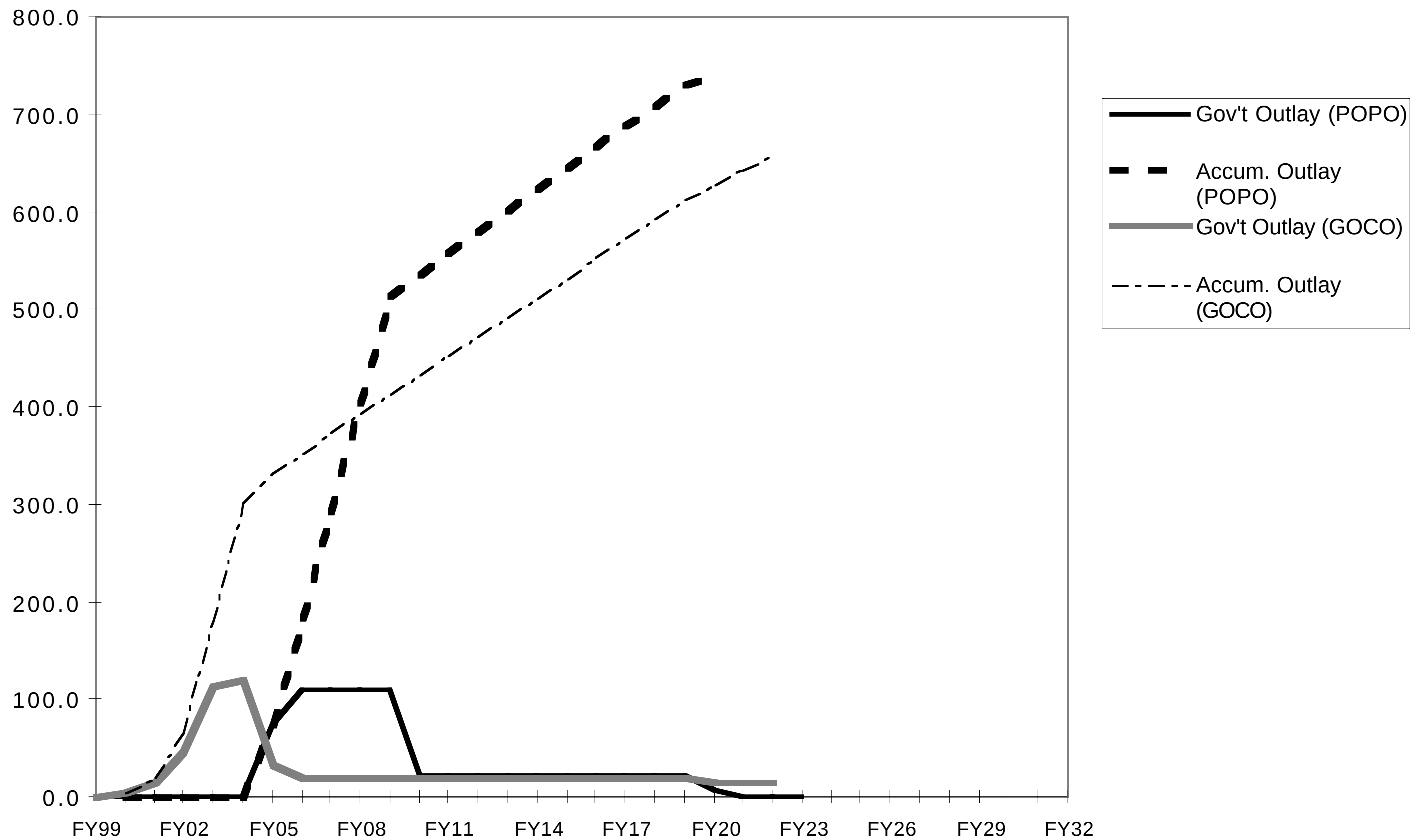


Figure 3.4 Funding profiles GOCO vs. POPO — U3O8/AHF 15 Operating Years (w/5 year loan payback time in POPO case)

Activity ID	Activity Description	Orig Dur	Early Start	Early Finish
MILESTONES				
GENERAL				
10	Record of Decision	0		30JUN99*
20	Site Selection	0		30SEP99*
30	Select A/E	0		30JUN00*
35	DOE Design Review	0		30JUN01
40	Authorize Construction	0		30SEP01
50	PSAR	0		30APR01*
45	Select Construction Contractor	0		31MAR02*
55	FSAR Approved by DOE	0		30JUN04*
60	End of Construction	0		30JUN04*
65	DOE Design/Operation Reviews	0		31DEC04*
70	Start-up & Full Operations	0		31DEC04*
PROJECT MANAGEMENT				
GENERAL				
100	DOCDR	6	01JUL99	31DEC99
105	A/E Proposal/Selection	6	01JAN00	30JUN00
110	Site-Specific EIS	18	01NOV99	30APR01
130	Permitting & Licensing	48	01JUL00	30JUN04
DESIGN / ENGINEERING				
GENERAL				
200	Preliminary Design	12	01JUL00	30JUN01
400	Detailed Design	24	01JUL01	30JUN03
550	Construction Support	27	01APR02	30JUN04
PROCUREMENT				
GENERAL				
600	Procurement	33	01OCT01	30JUN04
CONSTRUCTION				
PHASE 1 - PROCESS BUILDING AND SUPPORT BUILDINGS		27	01APR02	30JUN04
PHASE 2 - STORAGE AREA		18	01OCT02	31MAR04

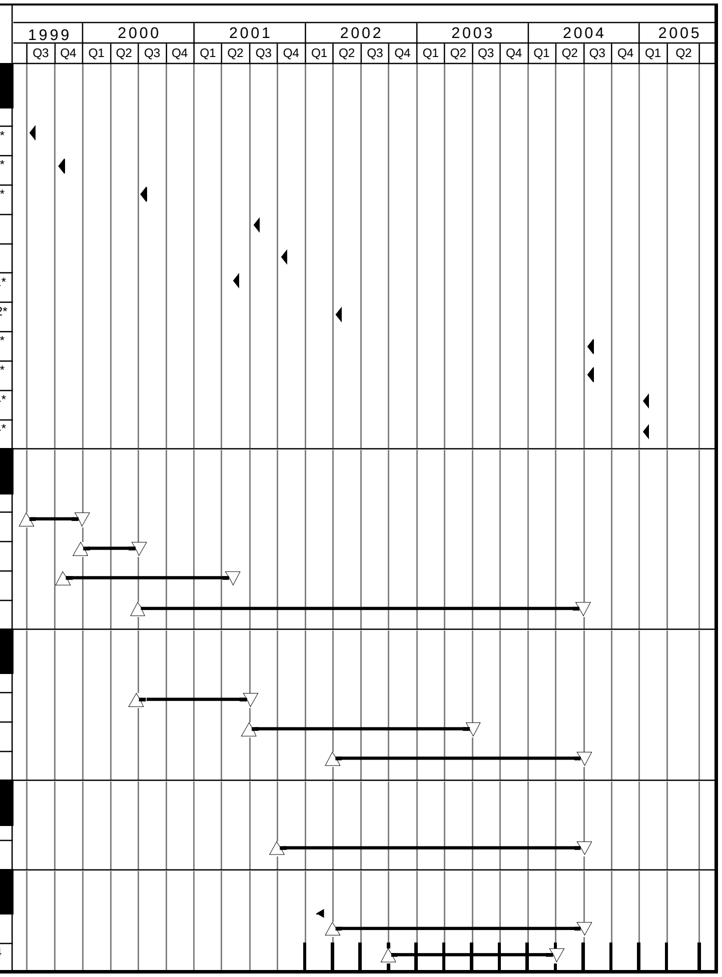


Figure 3.5 U3O8/AHF Plant, 25 Year Government Owned and Contractor Operated Preliminary Project Schedule

Table 3.1 Preconceptual Facility Design Summary

Description/case	**U3O8/AHF**	**UO2/AHF**	**U3O8/AHF/CaF2**	**U3O8/CaF2**	**U3O8/AHF**
Operating Time	**25 yrs**				**15 yrs**
DUF6 Feed	18,000 MT/yr				30,000 MT/yr
DUF6 Cylinders	1,472 cylinders/yr (5.1 cylinders/day)				2,461 cyl/yr (8.5 cyl/day)
Uranium Product	U3O8	93% UO2 agg.	U3O8	U3O8	U3O8
Quantity (MT/yr)	14,352	14,846	14,352	14,352	23,920
Packages (per yr)	1,758 4x4x7 ft bins	1,926 4x4x4 ft boxes	1,758 4x4x7 ft bins	1,758 4x4x7 ft bins	2,930 4x4x7 ft bins
On-Site Storage	1 yr	1 yr	1 yr	1 yr	1 yr
Disposition	Return to DOE				
Fluorine Product	AHF	AHF	AHF/CaF2	CaF2	AHF
Quantity (MT/yr)	5,962	5,944	5,962/11,966	11,966	9,936
Packages (per yr)	1.6 million gal	1.6 million gal	1.6 million gal/ 2,639 bins	2,639 4x4x7 ft bins	2.7 million gal
On-Site Storage	2 months	1 yr	2 mo./1 yr	1 yr	2 months
Disposition	Sales	Sales	Sales/DOE	DOE	Sales
Empty cylinders	Return to DOE				
No. of Employees (POPO case) (GOCO case)	 179 189	 191 —	 183 —	 — 193	 208 218
Site size (acres)	36	37	39	36	45
Process Bldg. (sq ft)	42,000	58,000	46,000	42,000	58,000

Table 3.2 Comparison of DUF6 Integrated Plant Cost Estimates

	U3O8/AHF	U3O8/AHF	U3O8/AHF	U3O8/AHF	UO2/AHF	U3O8/AHF/CaF2* (100% AHF)	U3O8/AHF/CaF2* (100% CaF2)	U3O8/CaF2
	25 Years-POPO	15 Years-POPO	25 Years-GOCO	15 Years-GOCO	25 Years-POPO	25 Years-POPO	25 Years-POPO	25 Years-GOCO
Facility Capital Cost	197	274	222	309	236	231	231	220
Annual O&M Cost	26	33	28	35	28	27	30	31
Total Operating Cost	672	510	717	541	723	689	752	795
Decon &Decommissioning	20	27	22	31	24	23	23	22
NEPA/Licensing	5	5	5	5	5	5	5	5
Lifecycle Cost	**894**	**816**	**966**	**886**	**988**	**948**	**1,011**	**1,043**
Byproduct Sale Revenue	229	229	229	229	229	229	—	—
Construction Loan Interest	179	240	—	—	212	208	208	—
Total Funding Outlay	**845**	**827**	**738**	**657**	**971**	**927**	**1,219**	**1,043**

Notes: Capital cost includes facility design and construction costs

Total operating cost includes startup and O&M costs over plant operating years

Revenue assumes 70¢/lb from AHF sales

Construction loan assumes @8.5% interest and 10 years payback time for privately owned cases

Funding outlay in POPO cases is payment to cover break-even cost only, no profits included.

* a single plant operated for either AHF or CAF2 production

4. Base Case: DUF6 Conversion to U3O8/AHF

4.1 Introduction

About 700,000 metric tons (MT) of depleted uranium hexafluoride (DUF6) are currently stored at the Paducah, Portsmouth and Oak Ridge sites. Public Law 105-204 requires the DOE to submit to Congress a plan to ensure that all funds accrued on the books of USEC for disposition of DUF6 will be used for the construction and operation of plants to treat and recycle the DUF6. The Department of Energy's Initial Plan calls for construction to begin in the year 2002 time frame.

A base case conversion plant is presented in this section to examine the costs and issues involved in a 2002 time frame for construction start. This study case is based on a conversion plant using a dry process to convert DUF6 to uranium oxide (U3O8) and anhydrous hydrogen fluoride (AHF) as final products.

A preconceptual plant design, rough cost estimate, and preliminary project schedule were developed for four base case options (see Section 4.2). The conversion plant includes capabilities for DUF6 cylinder preparation, conversion of DUF6 to uranium oxide and fluorine byproducts, empty cylinder treatment for disposal, and interim storage for oxide and byproducts.

Significant design bases for the conversion plant include:

- The plant will convert DUF6 to U3O8 by a dry process. Hydrogen fluoride (HF) off-gas will be treated to produce AHF and a minor quantity of calcium fluoride (CaF2).
- The plant capacity will be designed to process a DUF6 inventory of 36,910 cylinders (450,000 MT DUF6) over the life of the plant.
- Storage will be provided for one year production of U3O8 and CaF2 product and two months production of AHF.
- The AHF product is sold by the DOE or plant owner (depending on the case options described in Section 4.2) to commercial users. The U3O8 and CaF2 products are retained by the DOE, if the plant is government owned, or returned to the DOE, if the plant is privately owned.
- To bound costs associated with empty cylinders, assume all empty cylinders will be washed, compacted, and returned to the DOE for disposal.
- The plant will be located at a DOE owned site at or near a gaseous diffusion plant and include the support facilities and infrastructures/utilities needed for a greenfield facility.
- The design will consider addition of future process and storage buildings.

4.2 Description of Case Options

The construction and operation of the U3O8/AHF conversion plant is based on one of two basic scenarios: the plant will be government-owned and contractor-operated in conformance with DOE standards (GOCO), or the plant will be under private ownership and operation with DOE regulations (POPO). In addition, case options were developed for both 25-year operations and 15-year operations, which gives a total of four options. Where applicable, the differences between these four case options are discussed.

For the POPO cases, the assumed guaranteed maximum feed rate per annum is the total quantity of DUF6 (450,000 MT) divided by the product of the total number of years assumed to process this quantity and the plant availability factor. The guaranteed minimum feed rate per annum is 95% of the guaranteed maximum feed rate. It is also assumed there is no government financing, i.e., private financing only.

4.3 Summary of Results

A 2002 construction start depends on the key milestone dates for site selection, selection of primary contractor and construction contractor, and construction approval. The schedule includes NEPA activities, as a site-specific Environmental Impact Study (EIS) will be required, and DOE regulatory activities. The amount of U3O8 storage provided affects cost and may need additional study. Process design criteria for DUF6 cylinder vaporization, conversion reaction chamber, HF distillation, and empty cylinder treatment are necessary to ensure successful facility design and operation.

Typical production data for the DUF6 to U3O8/AHF conversion plants for both 25-year and 15-year operations are presented in Table 4.1. A summary comparison of DUF6 conversion plant cost estimates for the four case options is provided in Table 4.2. For more cost estimate details, see Section 4.6.

Specific results for each of the four case options are summarized below.

4.3.1 Government Owned and Government Operated with 25 Year Operations (GOCO/25)

The plant annually processes 18,000 MT of DUF6 contained in 1,476 cylinders to produce 14,352 MT of U3O8, 5,962 MT of AHF, 269 MT of CaF2, and 2,000 MT of empty cylinder metal waste. The plant, which includes a one year storage capacity for U3O8 and CaF2 and two months storage capacity for AHF, occupies about 36 acres. Additional storage capacity would require about 5 acres for each year of additional U3O8 storage.

The construction capital cost estimate is $188 million for the plant facilities. The engineering cost is about $34 million. Each year of additional storage would be $22 million for U3O8. These costs are in 1st Quarter FY2000 dollars.

The annual operation and maintenance (O&M) cost is about $28 million. The O&M cost does not include disposal of empty cylinder metal. Cost for NEPA, regulatory and licensing activities are estimated at $5 million. Decontamination and decommissioning (D&D) cost is estimated at $22 million.

The preliminary schedule assumes selection of an A/E contractor in June 2000. The schedule shows plant engineering design starting in July 2000, construction beginning in April 2002, plant completion in June 2004, and full operation beginning in December 2004. Peak engineering personnel is 80 persons and peak employment during construction is about 430 persons. Plant employment during operations is 189 persons.

4.3.2 Government Owned and Government Operated with 15 Year Operations (GOCO/15)

The plant annually processes 30,000 MT of DUF6 contained in 2,461 cylinders to produce 23,920 MT of U3O8, 9,936 MT of AHF, 449 MT of CaF2, and 3300 MT of empty cylinder metal waste. The plant, which includes a one year storage capacity for U3O8 and CaF2 and two months storage capacity for AHF, occupies about 45 acres. Additional storage capacity would require about 7 acres for each year of additional U3O8 storage.

The construction capital cost estimate is \$262 million for the plant facilities. The engineering cost is about \$47 million. Each year of additional storage would be \$33 million for U_3O_8. These costs are in 1st Quarter FY2000 dollars.

The annual operation and maintenance (O&M) cost is about \$35 million. The O&M cost does not include disposal of empty cylinder metal. Cost for NEPA, regulatory and licensing activities are estimated at \$5 million. Decontamination and decommissioning (D&D) cost is estimated at \$31 million.

The preliminary schedule assumes selection of an A/E contractor in June 2000. The schedule shows plant engineering design starting in July 2000, construction beginning in April 2002, plant completion in December 2004, and full operation beginning in June 2005. Peak engineering personnel is 110 persons and peak employment during construction is about 510 persons. Plant employment during operations is 218 persons.

4.3.3 Privately Owned and Privately Operated with 25 Year Operations (POPO/25)

The plant annually processes 18,000 MT of DUF_6 contained in 1,476 cylinders to produce 14,352 MT of U_3O_8, 5,962 MT of AHF, 269 MT of CaF_2, and 2,000 MT of empty cylinder metal waste. The plant, which includes a one year storage capacity for U_3O_8 and CaF_2 and two months storage capacity for AHF, occupies about 36 acres. Additional storage capacity would require about 5 acres for each year of additional U_3O_8 storage.

The construction capital cost estimate is \$172 million for the plant facilities. The engineering cost is about \$25 million. Each year of additional storage would be \$20 million for U_3O_8. These costs are in 1st Quarter FY2000 dollars.

The annual operation and maintenance (O&M) cost is about \$26 million. The O&M cost does not include disposal of empty cylinder metal. Cost for NEPA, regulatory and licensing activities are estimated at \$5 million. Decontamination and decommissioning (D&D) cost is estimated at \$20 million.

The preliminary schedule assumes selection of a private plant contractor in April 2000. The schedule shows plant engineering design starting in May 2000, construction beginning in November 2001, plant completion in January 2004, and full operation beginning in July 2004. Peak engineering personnel is 70 persons and peak employment during construction is about 400 persons. Plant employment during operations is 179 persons.

4.3.4 Privately Owned and Privately Operated with 15 Year Operations (POPO/15)

The plant annually processes 30,000 MT of DUF_6 contained in 2461 cylinders to produce 23,920 MT of U_3O_8, 9936 MT of AHF, 449 MT of CaF_2, and 3300 MT of empty cylinder metal waste. The plant, which includes a one year storage capacity for U_3O_8 and CaF_2 and two months storage capacity for AHF, occupies about 45 acres. Additional storage capacity would require about 7 acres for each year of additional U_3O_8 storage.

The construction capital cost estimate is \$240 million for the plant facilities. The engineering cost is about \$34 million. Each year of additional storage would be \$30 million for U_3O_8. These costs are in 1st Quarter FY2000 dollars.

The annual operation and maintenance (O&M) cost is about \$33 million. The O&M cost does not include disposal of empty cylinder metal. Cost for NEPA, regulatory and licensing activities are estimated at \$5 million. Decontamination and decommissioning (D&D) cost is estimated at \$27 million.

The preliminary schedule assumes selection of a private plant contractor in April 2000. The schedule shows plant engineering design starting in May 2000, construction beginning in November 2001, plant completion in July 2004, and full operation beginning in January 2005. Peak engineering personnel is 90 persons and peak employment during construction is about 480 persons. Plant employment during operations is 208 persons.

4.4 Conversion Process Description

Depleted uranium hexafluoride (DUF6) is processed to produce U3O8 and AHF. For 25-year operation, the average throughput is 5 cylinders per day (5,670 lb/hr UF6). For 15-year operation the average throughput is 8.5 cylinders per day (9,450 lb/hr UF6). These figures are based on 80% plant availability (7,000 hours/yr or 292 days/yr). The process block flow diagrams are shown in Figures 4.1a and 4.1b, respectively. For 25-year operation, major process equipment includes four steam autoclaves, six hot air ovens, four reaction chamber lines, U3O8 compaction and bin loading system, an HF distillation system, off-gas scrubbing system, neutralization/grouting system, two empty cylinder washing machines and one cylinder crusher. For 15-year operation, major process equipment includes six steam autoclaves, nine hot air ovens, six reaction chamber lines, U3O8 compaction and bin loading system, two HF distillation systems, off-gas scrubbing system, neutralization/grouting system, four empty cylinder washing machines and one cylinder crusher.

The DUF6 is shipped by truck from the cylinder yards at the gaseous diffusion plant to an outdoor storage pad at the Conversion Facility. The cylinder is moved into the Process Building for inspection and preparation. The cylinders are loaded into steam-heated autoclaves to vaporize the DUF6 for feeding into the conversion process. Cylinders with questionable integrity are loaded into hot air ovens where the solid DUF6 sublimes into a gas under vacuum. This avoids melting the DUF6 and pressurizing the cylinder, which occurs when using an autoclave. Several of the cylinders may be substandard based on the DUF6 Engineering Analysis Report (p. 6.1-4-5). Four autoclaves and six ovens are provided for 25-year operation; six autoclaves and nine ovens are provided for 15-year operation.

The DUF6 gas is converted to U3O8 in a series of two reaction chambers, where it is mixed with an HF/water vapor mixture in the first reaction chamber and with steam in the second reaction chamber. The chemical reactions are:

$$UF6 + 2\ H_2O \text{ ---> } UO2F_2 + 4\ HF$$

$$3\ UO2F_2 + 3\ H_2O \text{ ---> } U3O8 + 6\ HF + 0.5\ O_2$$

For 25-year operation, four reaction lines are provided to meet the required throughput. (Six lines are provided in the 15-year scenario). The U3O8 product is cooled, compacted to increase its bulk density, and packaged in metal bins. The 100 cu ft bins are about 4x4x7 ft tall and hold 9 tons (8.16 MT) of U3O8. The filled bins are transferred to the U3O8 Storage Building.

Reaction chamber off-gas containing HF, steam and oxygen is filtered to remove uranium particulates. The off-gas then flows to an HF distillation system, which concentrates the mixture to produce anhydrous HF in the overhead product. The AHF is collected, sampled, and pumped to large storage tanks in the HF Storage Building, where the AHF is loaded into railcars or tank trucks for delivery to customers. The AHF is expected to contain less than 1 ppm uranium.

The aqueous hydrogen fluoride bottoms stream from HF distillation is collected, vaporized and recycled to the first reaction chamber. To prevent the buildup of impurities in the recycle stream, a small fraction is withdrawn. This purge stream is neutralized with hydrated lime, mixed with cement and water to form a grout, and packaged in drums for disposal.

Off-gas from the distillation column, primarily oxygen and air inleakage, flows to the scrubber system. Residual HF in the off-gas is removed by scrubbing with a potassium hydroxide (KOH) solution. The off-gas is then HEPA-filtered and discharged to the atmosphere. The spent scrub solution is regenerated with hydrated lime ($Ca(OH)_2$), which produces a calcium fluoride (CaF2) byproduct. The chemical reactions are:

$HF + KOH \text{--->} KF + H_2O$

$2\ KF + Ca(OH)_2 \text{--->} CaF2 + 2\ KOH$

The CaF2 is separated by filtering, washed with water, dried and loaded into drums. The drums, containing 700 lb of CaF2, are transferred to the CaF2 Storage Building. The CaF2 is expected to contain less than 1 ppm uranium.

After vaporization, the empty cylinders are transferred to an outdoor pad and stored for three months. This allows for radioactive decay of non-volatile daughter products in the cylinder. The cylinders are then brought into the Process Building, washed with water, crushed, and loaded into boxes. Each 6x14x3 ft high box contains about 9,000 lb of metal from three crushed cylinders. The filled boxes are stored in the Waste Storage Building and transported to the gaseous diffusion plant for disposition. The cylinder wash effluents are fed into the main conversion processes. Major process materials and annual quantities are summarized below:

Major Input Streams	Major Output Streams
GOCO and POPO 25 years	
Depleted Uranium Hexafluoride 18,000 MT/yr 1476 cylinders/yr	Uranium Oxide (U_3O_8) 14,352 MT/yr 1758 4x4x7 (H) ft bins/yr (18,000 lb/bin) or 24,344 55-gal drums/yr (1300 lb/drum)
Hydrated Lime $Ca(OH)_2$ 325 MT/yr 8700 ft^3/yr	Anhydrous Hydrogen Fluoride (HF) 5962 MT/yr 1.64 million gal/yr
Cement 154 MT/yr 2900 ft^3/yr	Calcium Fluoride (CaF_2) 269 MT/yr 848 55-gal drums/yr (700 lb/drum)
	Empty Cylinder Metal Waste 2000 MT/yr 492 6x14x3 (H) ft boxes/yr (9000 lb/box)
	Grouted Waste 367 MT/yr 1012 55-gal drums/yr (800 lb/drum)
GOCO and POPO 15 years	
Depleted Uranium Hexafluoride 30,000 MT/yr 2461 cylinders/yr	Uranium Oxide (U_3O_8) 23,920 MT/yr 2930 4x4x7 (H) ft bins/yr (18,000 lb/bin) or 40,572 55-gal drums/yr (1300 lb/drum)
Hydrated Lime $Ca(OH)_2$ 542 MT/yr 14,500 ft^3/yr	Anhydrous Hydrogen Fluoride (HF) 9936 MT/yr 2.73 million gal/yr
Cement 257 MT/yr 4900 ft^3/yr	Calcium Fluoride (CaF_2) 449 MT/yr 1414 55-gal drums/yr (700 lb/drum)
	Empty Cylinder Metal Waste 3300 MT/yr 820 6x14x3 (H) ft boxes/yr (9000 lb/box)
	Grouted Waste 612 MT/yr 1687 55-gal drums/yr (800 lb/drum)

4.5 Conversion Plant Description

The Conversion Facility is assumed to be constructed on a DOE site at a greenfield location at or near a gaseous diffusion plant. The Conversion Facility occupies about 36 acres (25-year operation) or about 45 acres (15-year operation). Additional storage buildings for U3O8 could be built adjacent or at a nearby location. Each additional one year increment of U3O8 storage occupies 5 acres (25-year operation) or about 7 acres (15-year operation). Conceptual site plans for the Conversion Facility are shown in Figures 4.2a and 4.2b.

The Conversion Facility includes full and empty cylinder storage pads, the Process Building, a U3O8 Storage Building, an HF Storage Building , a CaF2 Storage Building, a Waste Storage Building and support facilities. The site plan considers addition of future process facilities such as uranium metal or sintered uranium pellets.

The Conversion Facility will be designed and constructed in compliance with DOE Orders and applicable regulations and codes, and will meet the intent of NRC standards. In general, a graded approach as established in DOE Order 420.1 is used for the design of all structures, systems, and components (SSC) in the plant facilities. All SSC's will be assigned a Natural Phenomena Performance Category using the criteria in the DOE Standards DOE-STD-1020-94 and DOE-STD-1021-93 during the design phase.

In the absence of a hazard analysis, it is assumed that the Process Building is performance category PC-3 to control and confine hazardous material. The building structure is reinforced concrete construction in the processing areas. The remainder of the building housing the personnel support area is steel frame, metal siding construction. The Process Building is 30 ft high in the processing areas and 18 ft high in the support areas. HVAC equipment is located on a mezzanine level. The process room air is filtered through one stage of HEPA filters prior to discharge to atmosphere. The Process Building general arrangements are shown in Figures 4.3a and 4.3b.

The U3O8 Storage Building and CaF2 Storage Building have a one year capacity. For 25-year operation, the U3O8 Building holds 1,760 bins stacked one high, and the CaF2 Building holds 850 drums stacked two high. For 15-year operation, the U3O8 Building holds 2,960 bins stacked one high, and the CaF2 Building holds 1,420 drums stacked two high. The Waste Building has a one month capacity for staging treated empty cylinders and process waste for transport offsite. The U3O8, CaF2, and waste storage buildings are assumed PC-2 to maintain storage function after the occurrence of a natural phenomena hazards event. These buildings are steel frame and concrete clad panel construction and are ventilated and lighted, but no heating, cooling or HEPA filtration is provided. Access aisles allow personnel to inspect the bins during storage. A general storage arrangement in the U3O8 Building is shown in Figure 4.4a and Figure 4.4b.

The HF Storage Building has a two month capacity with ten or sixteen 34,000-gallon storage tanks (25-year operation and 15-year operation, respectively). The HF Storage Building is assumed PC-3 to control and confine hazardous material. The building structure is reinforced concrete construction. The HF storage tanks are housed separately in cell rooms.

Plant operations are assumed to be continuous for 24 hours/day, 7 days/week, 52 weeks/year. Due to seven day per week operation, a fourth shift is necessary to account for normal days off for employees. For GOCO 25-year operation, the number of employees during operation is estimated to be 189 persons, with 69 employees on day shift and 40 each of the other three shifts. For GOCO 15-year operation, the number of employees during operation is estimated to be 218 persons, with 77 employees on day shift and 47 each of the other three shifts. For POPO 25-year operation, the number of employees during operation is estimated to be 179 persons, with 65 employees on day shift and 38 each of the other three shifts. For POPO 15-year operation, the number of employees during operation is estimated to be 208 persons, with 73 employees on day shift and 45 each of the other three shifts.

No allowance is included for plant medical or fire fighting personnel.

The numbers are estimated based on process operation labor and facility support labor requirements needed to operate the plant. See Table 4.3 for typical manpower estimates.

4.6 Cost Estimates

The cost estimates are rough order of magnitude estimates based on a preconceptual level design information.

The estimates do not include costs for plant design criteria development, cost of land, site qualifications, or extension of local roads and utility lines to the site boundary. The estimates take into account the procurement pricing, labor productivity, and indirect cost factors for a government project. Cost estimate bases are described in the Appendix.

The cost estimate results are summarized below:

	Government Owned and Government Operated Plant					
	15-Year Operation			25-Year Operation		
	Cost ($M)	Contin-gency ($M)	Total Cost ($M)	Cost $M)	Contin-gency ($M)	Total Cost $M
Conversion Facility						
Engineering	--	--	47	--	--	34
Plant Facilities Construction Cost	194	68	262	139	49	188
Startup Cost	--	--	14	--	--	12
Annual Operations and Maintenance Cost (O&M)	--	--	35	--	--	28
Decontamination and Decommissioning (D&D)	--	--	31	--	--	22
Additional Storage						
Engineering	--	--	2.6	--	--	1.8
U3O8 Storage (1 yr capacity) Construction Cost	29	4	33	19	3	22
NEPA/Licensing	--	--	5	--	--	5

	Privately Owned and Privately Operated Plant					
	15-Year Operation			25-Year Operation		
	Cost ($M)	**Contin-gency ($M)**	**Total Cost ($M)**	**Cost ($M)**	**Contin-gency ($M)**	**Total Cost $M**
Conversion Facility						
Engineering	--	--	34	--	--	25
Plant Facilities Construction Cost	178	62	240	128	44	172
Startup Cost	--	--	14	--	--	12
Annual Operations and Maintenance Cost (O&M)	--	--	33	--	--	26
Decontamination and Decommissioning (D&D)	--	--	27	--	--	20
Additional Storage						
Engineering	--	--	2.4	--	--	1.6
U3O8 Storage (1 yr capacity) Construction Cost	26	4	30	18	2	20
NEPA/Licensing	--	--	5	--	--	5

The construction capital costs are based on an engineering, procurement, and construction approach for a government project. Capital costs, see Tables 4.4a and 4.4b, are reported in 1st quarter fiscal year 2000 dollars (October 1999). Labor costs are based on local wage rates at a generic gaseous diffusion plant located in mid-U.S.A. The capital cost estimate utilized historical cost data, estimating manuals, allowances and budgetary quotations. A 35% contingency was applied to the capital costs for the Conversion Facility and 15% for the subsequent Storage Facilities. These contingency levels are based on previous risk analysis on projects of similar scope and level of design details. Engineering cost was estimated at 18% of the capital costs for the Conversion Facility and 8% for the subsequent Storage Facilities. The lower percentages are used for the subsequent Storage Facilities because previous building engineering design can be reused. Product and waste container costs are included in the O&M costs. The D&D cost was estimated as 10% of the capital cost.

The O&M cost includes costs for materials, utilities, labor, waste disposal, and management and operation (M&O) contractor fees, see Tables 4.5a and 4.5b. Plant startup cost was assumed to be 65% of the annual O&M labor cost. The annual O&M cost does not include the cost for disposal of empty cylinder metal waste. If the empty cylinder metal is to be disposed as low-level waste (LLW), the estimated disposal cost for 25-year operation would range from $1 million to $12 million annually, depending on the disposal sites. For 15-year operation, the corresponding estimated disposal cost ranges from $1.7 million to $20 million. Revenue from sales of AHF is also not included in the O&M cost.

The annual expenditure required to support the construction and operation of the conversion plant case options are provided in Figures 4.6 through 4.11. The expenditure profiles are derived from loading the estimated capital and operating costs onto the project schedule. A constant FY2000 dollar value is used in the expenditure outlay because of the difficulty in accurately projecting the inflation rate for future years.

The life-cycle funding outlays for the various case options are summarized in the bottom line of Table 4.2. Note that byproduct sale revenue and construction loan interest are included. In the POPO cases, the total outlay is a break-even government payment that doesn't include profit. In addition to a 10-year payback time for the POPO cases, the expenditure outlays for a 5-year payback time were developed. The break-even payment for 5-year payback in the 15-year POPO case is \$738M as opposed to \$827M for a 10-year payback; and \$779M as opposed to \$845M in the 25-year POPO case.

4.7 Project Schedules

The estimated preliminary project schedules are shown in Figures 4.5 to 4.8. The schedule is based on a fast track premise with overlapping engineering phases and early procurement of some key equipment (most equipment is available in 12-18 month lead time) and a two-phase construction plan.

The reader is advised to consider these schedules illustrative, rather than definitive. There are large uncertainties in the timing or delays in the DOE regulatory processes leading to full operations.

4.7.1 GOCO/25

The schedule allows 3 years for engineering design and 2 years for construction. The estimated peak engineering personnel is 80 persons and peak employment during construction is 430 persons.

4.7.2 GOCO/15

The schedule allows 3 years for engineering design and 2.5 years for construction. The estimated peak engineering personnel is 110 persons and peak employment during construction is 510 persons.

4.7.3 POPO/25

The schedule allows 2.5 years for engineering design and 2 years for construction. The estimated peak engineering personnel is 70 persons and peak employment during construction is 400 persons.

4.7.4 POPO/15

The schedule allows 2.5 years for engineering design and 2.5 years for construction. The estimated peak engineering personnel is 90 persons and peak employment during construction is 480 persons.

4.8 Discussion and Issues

4.8.1 Process

Bins were used to package the U3O8 because of the space savings compared to 55-gallon drums. Using bins instead of drums reduces the storage building area by about 35%. Additional study is needed to determine the best storage container to use with the cost considerations on facilities and transport.

In cylinder washing, the empty cylinders are cleaned to remove the reactive fluoride materials inside the cylinder. It was assumed that the metal from washed empty cylinders is returned to the DOE for disposal. The residual uranium contaminated cylinders might require the cylinder metal to be disposed of as LLW. Alternate dispositions include recycling and reusing the radioactively-contaminated carbon steel for LLW containers for use in the nuclear industry or sufficiently decontaminating the metal for disposal as non-hazardous waste or scrap.

4.8.2 Facilities

Buildings for processing and storage were assumed to be performance category PC-2 or PC-3. A safety and accident analysis was not performed and is needed to determine the hazard classification and performance category. The appropriate structure, confinement and ventilation for buildings housing large quantities of U3O8 needs study.

The DUF6 Engineering Analysis Report has identified issues with federal (49CFR173.420) or ANSI N14.1 transportation requirements and overpressured, overfilled or substandard cylinders. The Report suggests that a new overpack be designed and licensed if filled substandard cylinders must be shipped from off-site. The cost of overpacks is not considered in the report. This transportation issue still needs to be resolved.

The preconceptual plant design is essentially a single line plant. Multiple autoclaves, ovens, and conversion reaction chambers are provided to obtain the design throughput. The HF distillation system, off-gas scrubber, and impurity neutralization units are single line systems with installed spares on maintenance-prone items such as pumps and filters. A RAM (reliability, availability, maintainability) analysis may help determine if this configuration is satisfactory and whether independent parallel lines might be desirable.

4.8.3 Cost Estimates

The cost estimates vary depending on the scenario under discussion, and differ depending on whether the plant is government owned and contractor operated or privately owned and operated. The major contributors to the capital cost are the Process Building including the structure and service systems. The major process equipment costs are the cylinder handling crane, autoclaves, hot air ovens and DUF6 compressors, conversion reaction chambers, distillation equipment, and cylinder tilt and roll wash stands. The cost to dispose of empty cylinder metal is not included in this report. If it is disposed as LLW, the disposal cost could be significant.

4.8.4 Schedule

The schedule shows a construction start early in the second quarter of year 2002. This appears to be attainable if the site selection, selection of contractor, and early approval for construction dates are met. The Record of Decision is expected to be issued by the end of June per the schedule shown in this report.

4.9 References

Initial Plan for the Conversion of Depleted Uranium Hexafluoride, as Required by Public Law 105-204, U.S. Department of Energy, 1999

Draft Engineering Analysis Report for the Long-Term Management of Depleted Uranium Hexafluoride, UCRL-AR-124080, Lawrence Livermore National Laboratory, May 1997

Uranium Hexafluoride: A Manual of Good Handling Practices, ORO-651, U.S. Department of Energy, October 1991

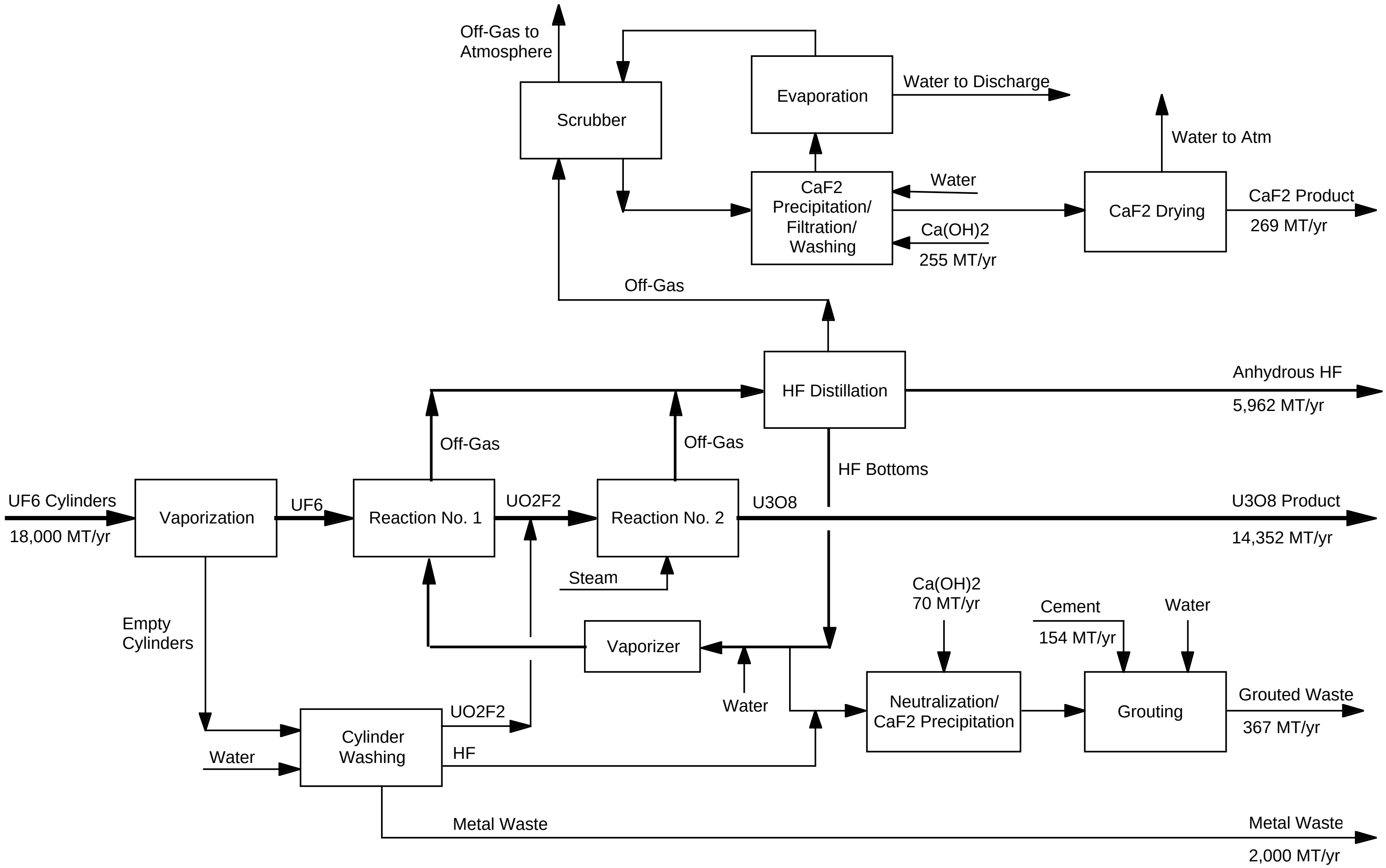


Figure 4.1a Process Block Flow Diagram
Conversion to U3O8 and AHF (25 yr)

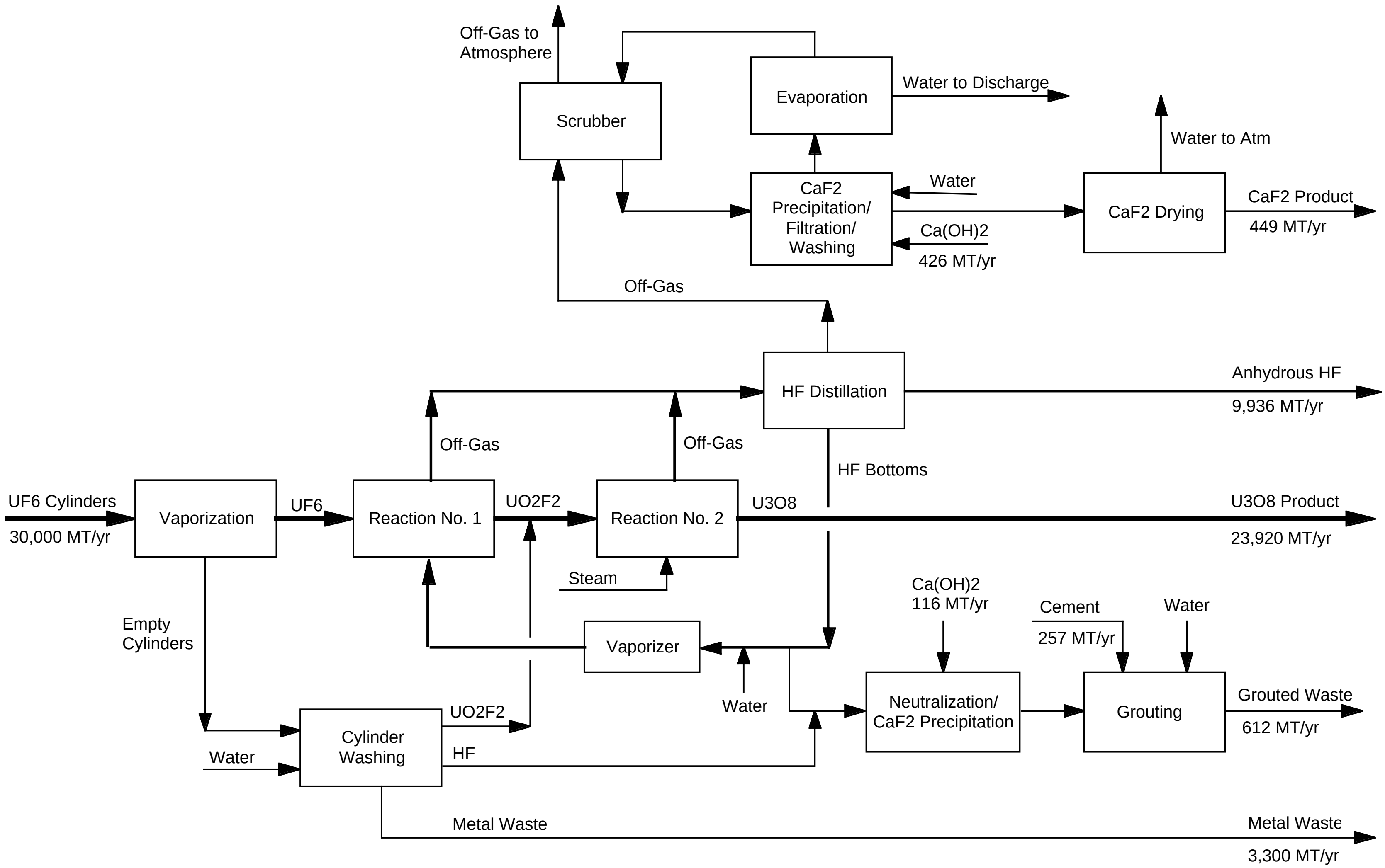


Figure 4.1b Process Block Flow Diagram
Conversion to U3O8 and AHF (15 yr)

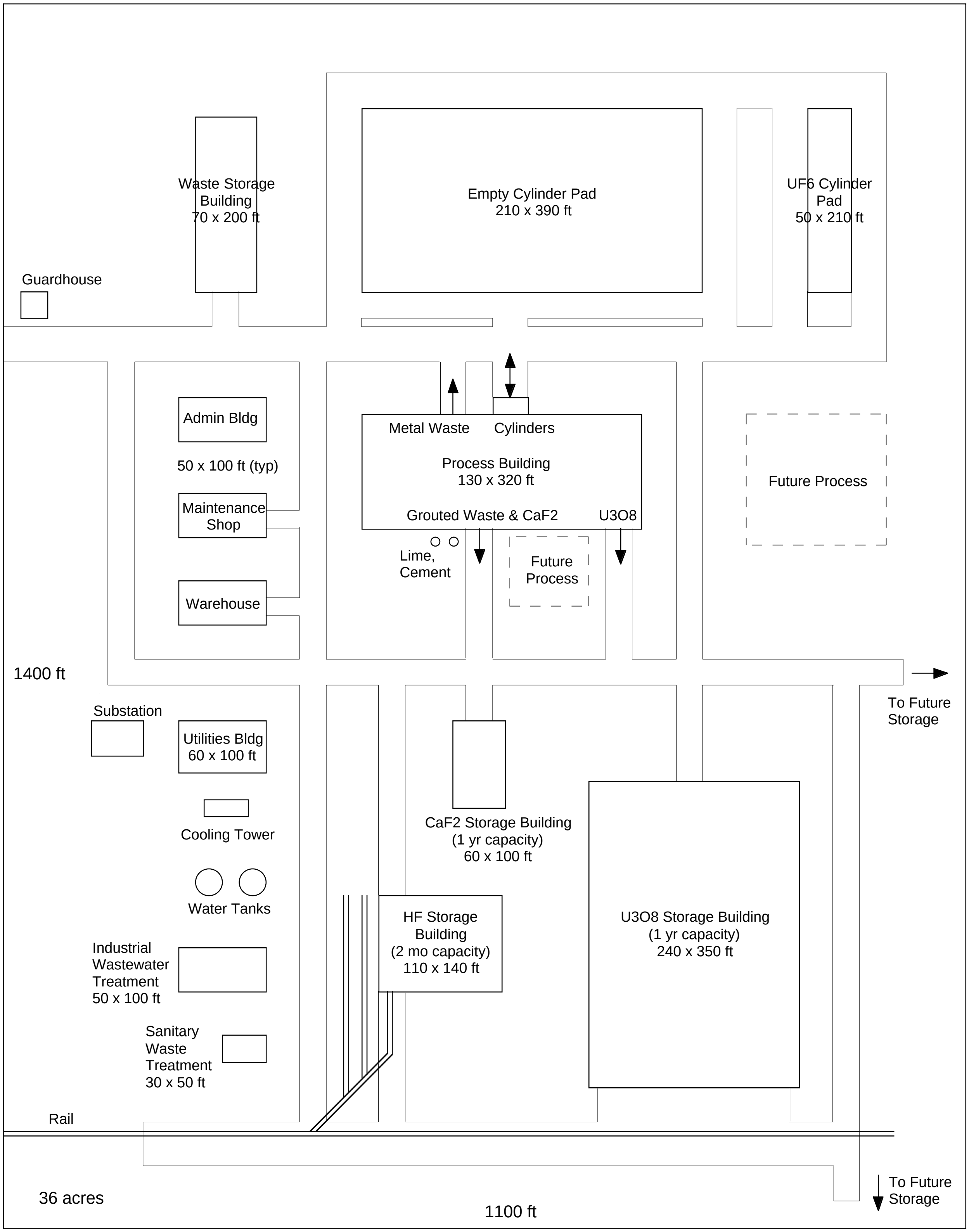


Figure 4.2a Facility Site Plan
Conversion to U3O8 and AHF (25 yr)

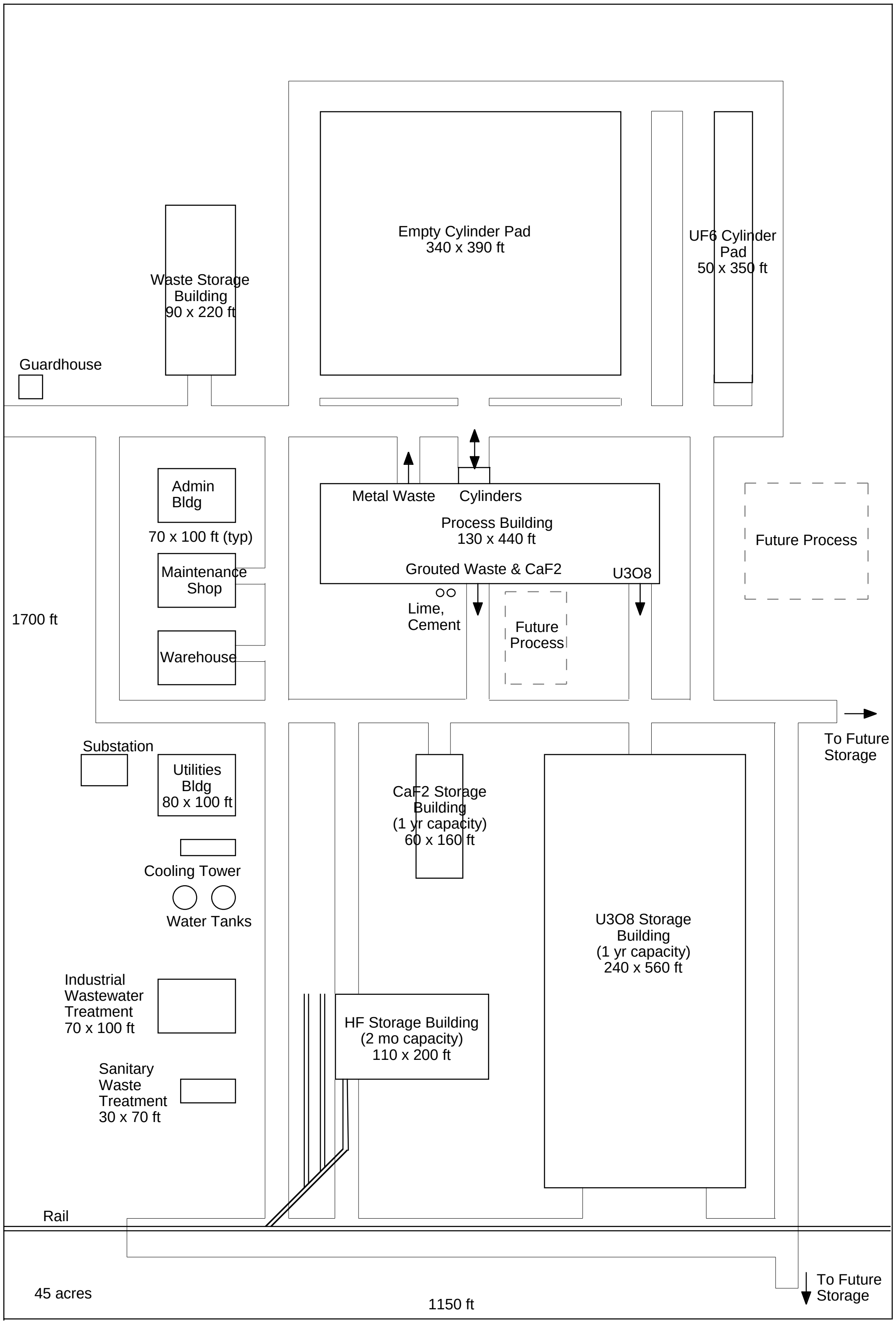


Figure 4.2b Facility Site Plan
Conversion to U3O8 and AHF (15 yr)

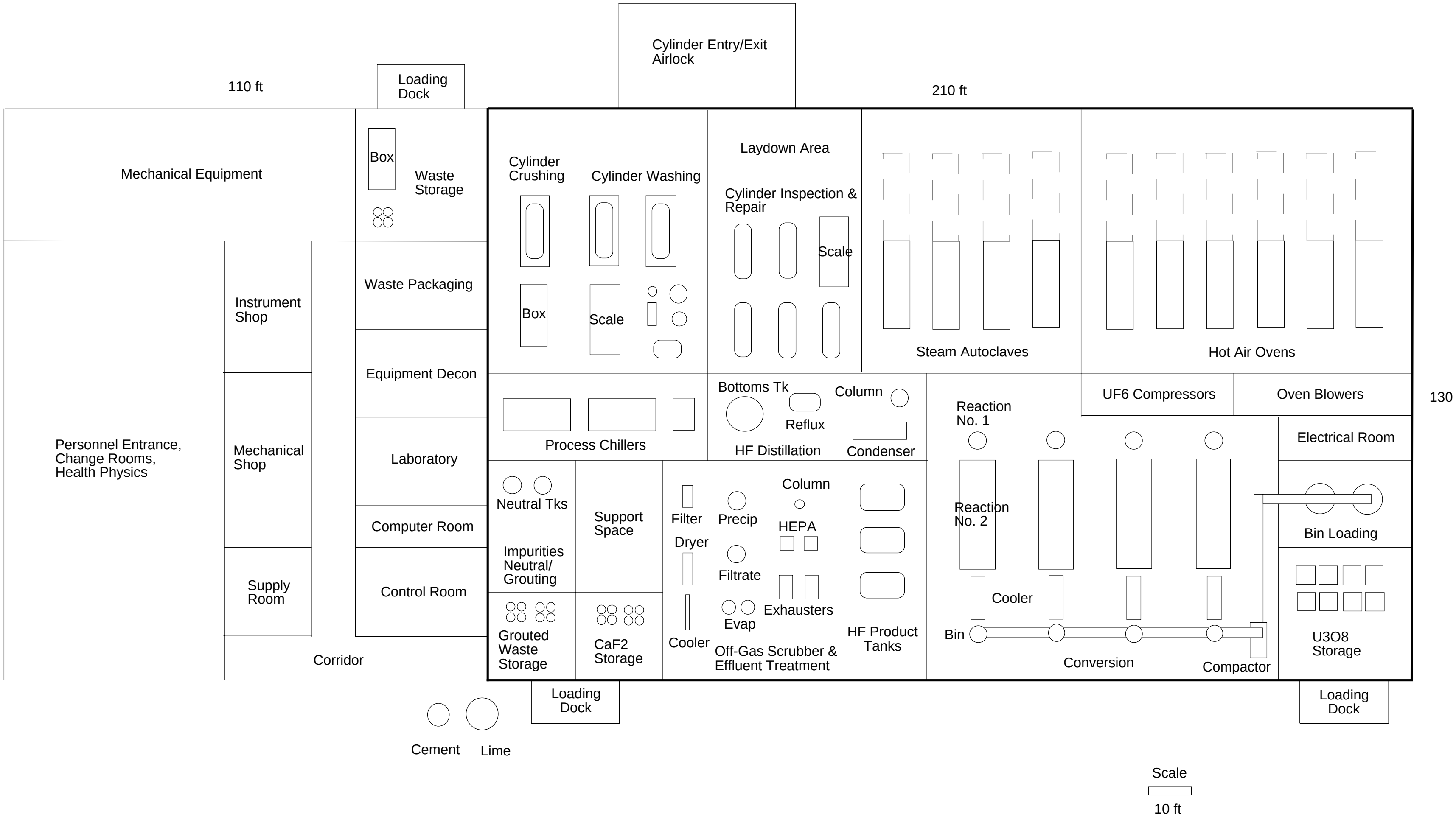


Figure 4.3a Process Building General Arrangement Conversion to U3O8 and AHF (25 yr)

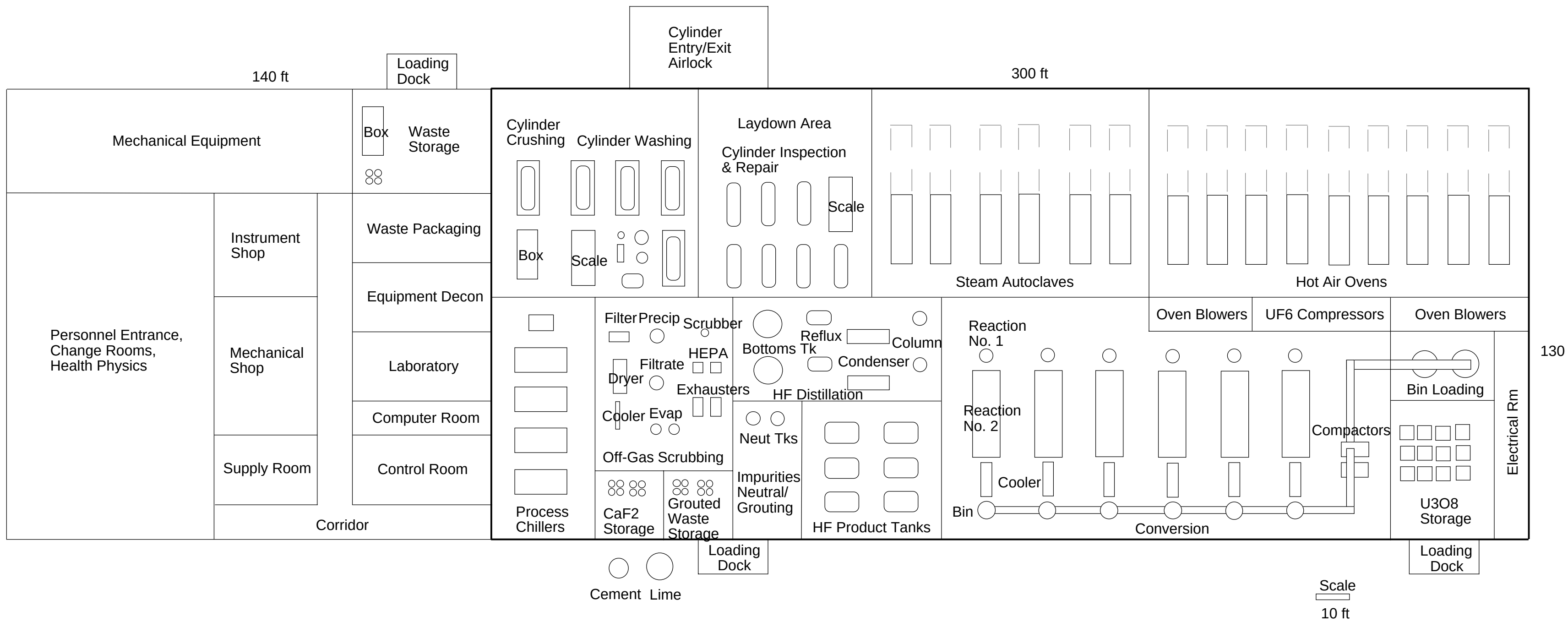


Figure 4.3b Process Building General Arrangement Conversion to U3O8 and AHF (15 yr)

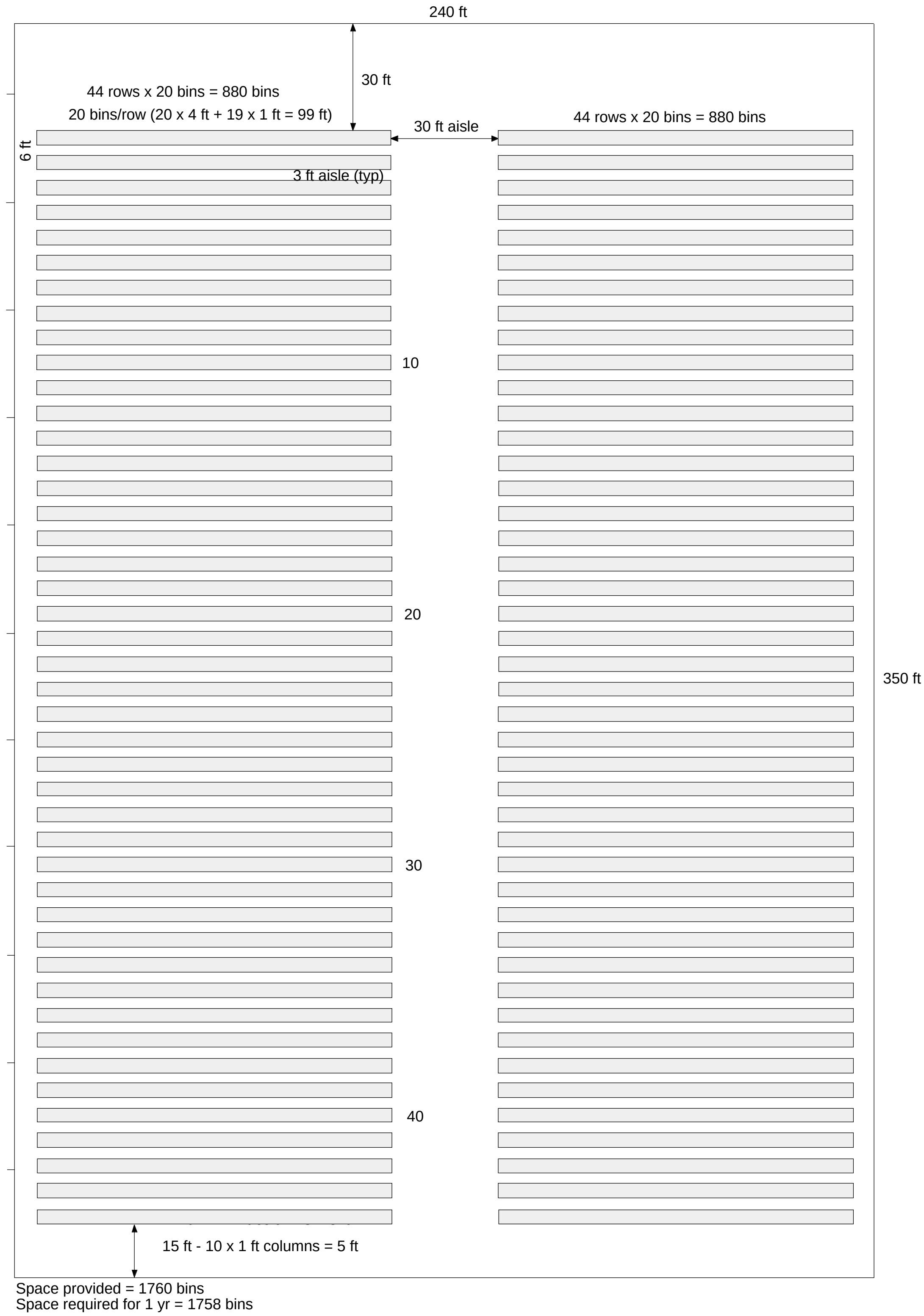
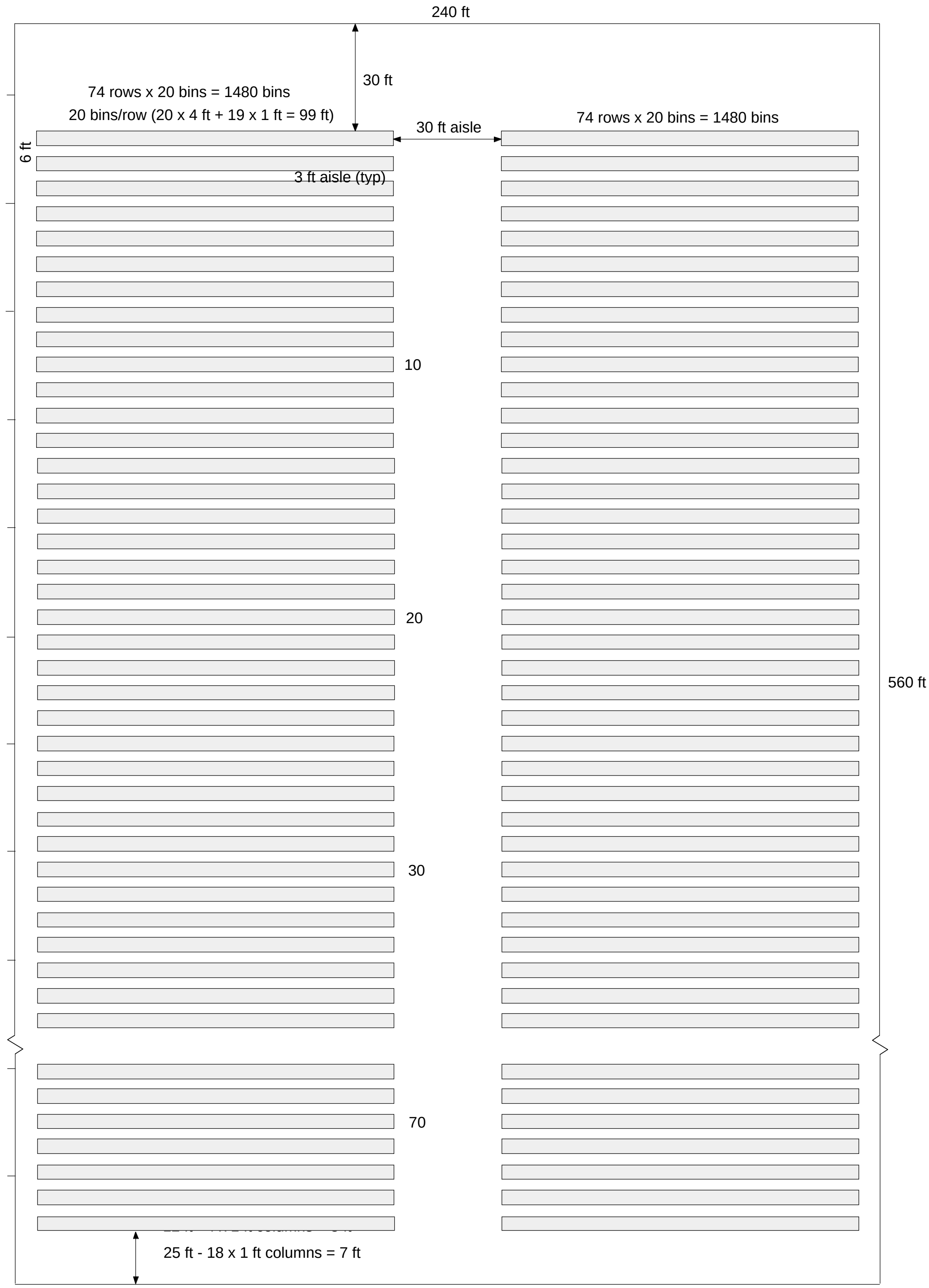


Figure 4.4a U3O8 Storage Building Plan
Conversion to U3O8 and AHF (25 yr)



Space provided = 2960 bins
Space required for 1 yr = 2930 bins

Figure 4.4b U3O8 Storage Building Plan
Conversion to U3O8 and AHF (15 yr)

Activity ID	Activity Description	Orig Dur	Early Start	Early Finish
MILESTONES				
GENERAL				
10	Record of Decision	0		30JUN99*
20	Site Selection	0		30SEP99*
30	Select A/E	0		30JUN00*
35	DOE Design Review	0		30JUN01
40	Authorize Construction	0		30SEP01
50	PSAR	0		30APR01*
45	Select Construction Contractor	0		31MAR02*
55	FSAR Approved by DOE	0		30JUN04*
60	End of Construction	0		30JUN04*
65	DOE Design/Operation Reviews	0		31DEC04*
70	Start-up & Full Operations	0		31DEC04*
PROJECT MANAGEMENT				
GENERAL				
100	DOCDR	6	01JUL99	31DEC99
105	A/E Proposal/Selection	6	01JAN00	30JUN00
110	Site-Specific EIS	18	01NOV99	30APR01
130	Permitting & Licensing	48	01JUL00	30JUN04
DESIGN / ENGINEERING				
GENERAL				
200	Preliminary Design	12	01JUL00	30JUN01
400	Detailed Design	24	01JUL01	30JUN03
550	Construction Support	27	01APR02	30JUN04
PROCUREMENT				
GENERAL				
600	Procurement	33	01OCT01	30JUN04
CONSTRUCTION				
PHASE 1 - PROCESS BUILDING AND SUPPORT BUILDINGS		27	01APR02	30JUN04
PHASE 2 - STORAGE AREA		18	01OCT02	31MAR04

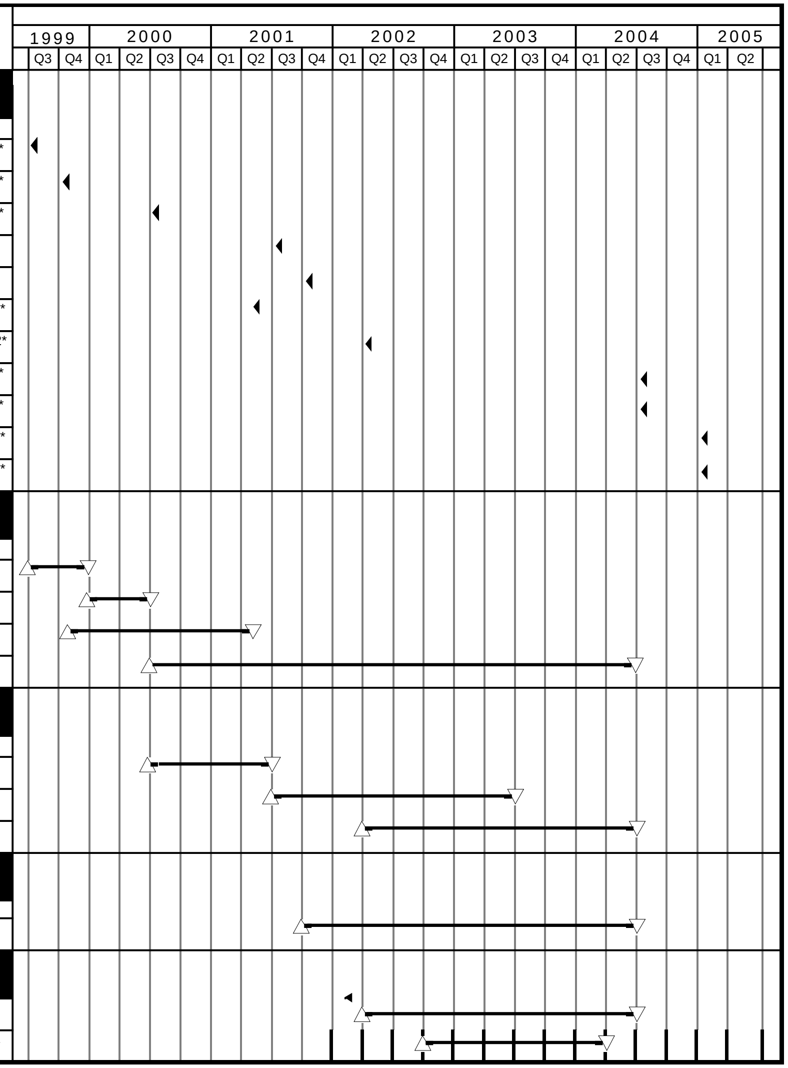


Figure 4.5 U3O8/AHF Plant, 25 Year Government Owned and Contractor Operated Preliminary Project Schedule

Activity ID	Activity Description	Orig Dur	Early Start	Early Finish
MILESTONES				
GENERAL				
10	Record of Decision	0		30JUN99*
20	Site Selection	0		30SEP99*
30	Select A/E	0		30JUN00*
35	DOE Design Review	0		30JUN01
40	Authorize Construction	0		30SEP01
50	PSAR	0		30APR01*
45	Select Construction Contractor	0		31MAR02*
55	FSAR Approved by DOE	0		30JUN04*
60	End of Construction	0		31DEC04*
65	DOE Design/Operation Reviews	0		30JUN05*
70	Start-up & Full Operations	0		30JUN05*
PROJECT MANAGEMENT				
GENERAL				
100	DOCDR	6	01JUL99	31DEC99
105	A/E Proposal/Selection	6	01JAN00	30JUN00
110	Site-Specific EIS	18	01NOV99	30APR01
130	Permitting & Licensing	54	01JUL00	31DEC04
DESIGN / ENGINEERING				
GENERAL				
200	Preliminary Design	12	01JUL00	30JUN01
400	Detailed Design	24	01JUL01	30JUN03
550	Construction Support	33	01APR02	31DEC04
PROCUREMENT				
GENERAL				
600	Procurement	39	01OCT01	31DEC04
CONSTRUCTION				
PHASE 1 - PROCESS BUILDING AND SUPPORT BUILDINGS		33	01APR02	31DEC04
PHASE 2 - STORAGE AREA		27	01OCT02	31DEC04

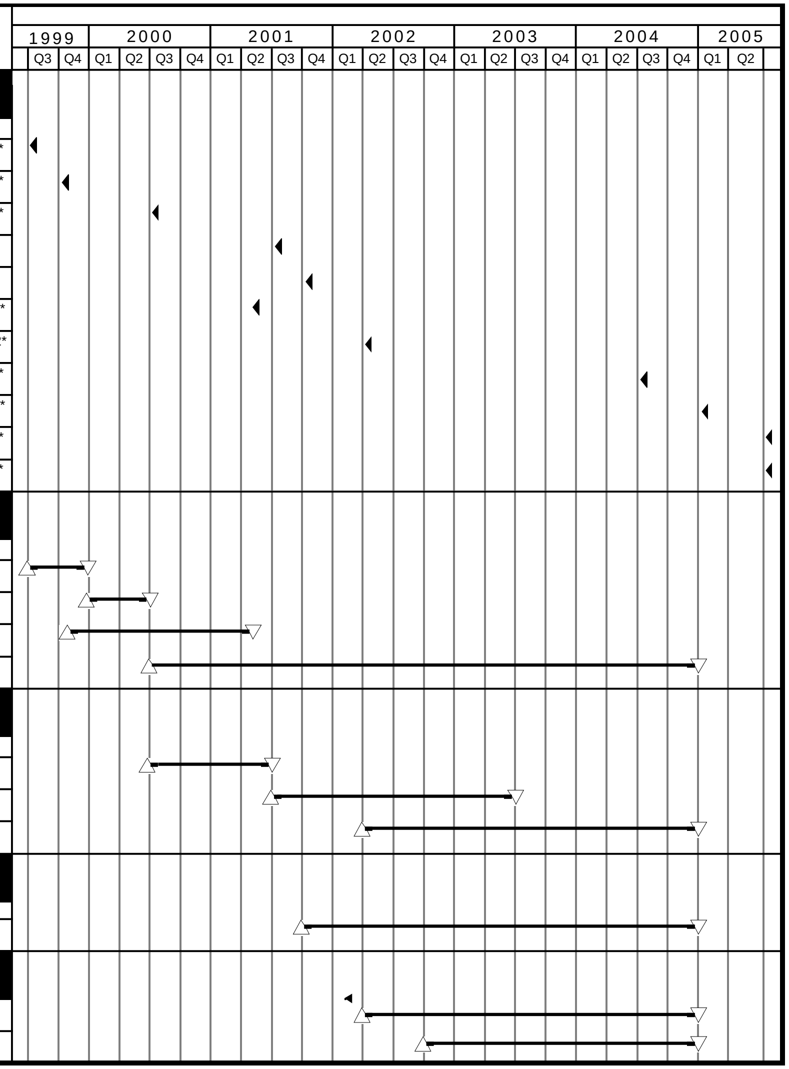


Figure 4.6 U3O8/AHF Plant, 15 Year Government Owned and Contractor Operated Preliminary Project Schedule

Activity ID	Activity Description	Orig Dur	Early Start	Early Finish
MILESTONES				
GENERAL				
10	Record of Decision	0		30JUN99*
20	Site Selection	0		30SEP99*
30	Primary Contractor Selection	0		30APR00*
35	DOE Design Review	0		31DEC00
40	Authorize Construction	0		31MAR01
50	PSAR	0		30NOV00*
45	Select Construction Contractor	0		31OCT01
55	FSAR Approved by DOE	0		31OCT03*
60	End of Construction	0		31JAN04*
65	DOE Design/Operation Reviews	0		31JUL04*
70	Start-up & Full Operations	0		31JUL04*
PROJECT MANAGEMENT				
GENERAL				
100	Project Definition	9	01MAY99	31JAN00
105	DOE Procurement Action	9	01AUG99	30APR00
110	Site-Specific EIS	18	01NOV99	30APR01
120	Primary Contrractor Evaluation	3	01FEB00	30APR00
130	Permitting & Licensing	44	01MAY00	31DEC03
DESIGN / ENGINEERING				
GENERAL				
200	Preliminary Design	12	01MAY00	30APR01
400	Detailed Design	24	01NOV00	31OCT02
550	Construction Support	27	01NOV01	31JAN04
PROCUREMENT				
GENERAL				
600	Procurement	33	01MAY01	31JAN04
CONSTRUCTION				
	PHASE 1 - PROCESS BUILDING AND SUPPORT BUILDINGS	27	01NOV01	31JAN04
	PHASE 2 - STORAGE AREA	15	01MAY02	31OCT03

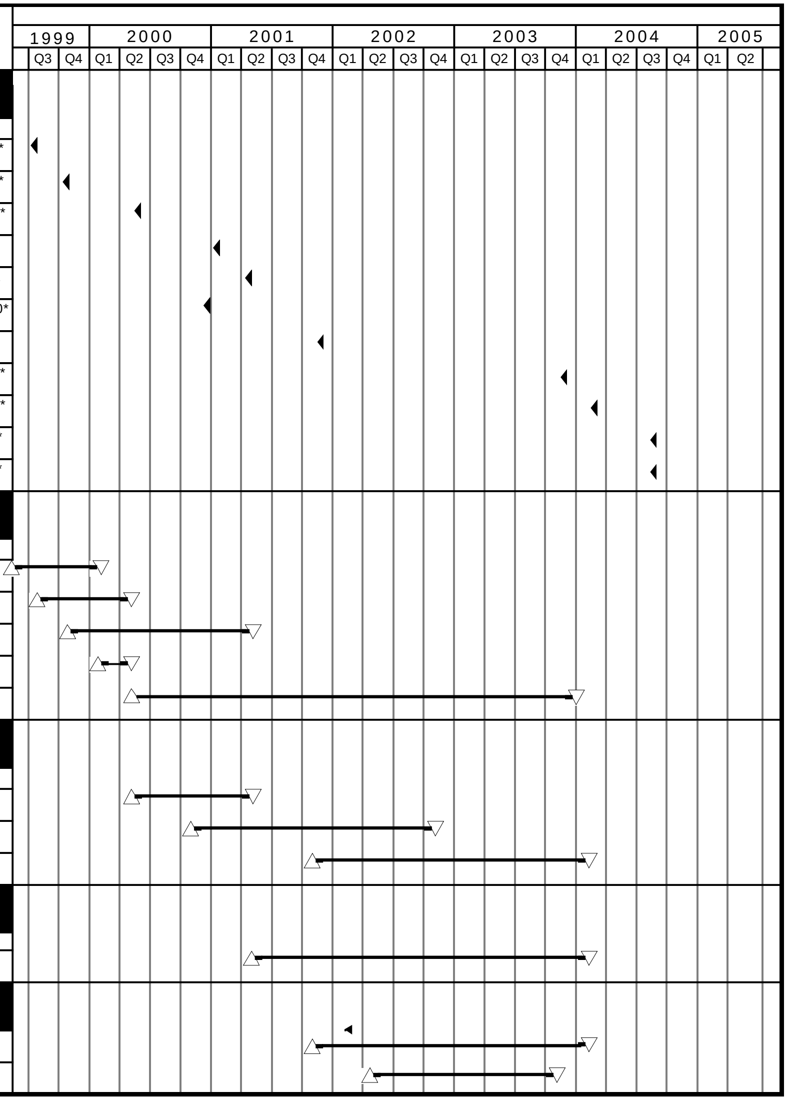


Figure 4.7 U3O8/AHF Plant, 25 Year Privately Owned and Operated Preliminary Project Schedule

Activity ID	Activity Description	Orig Dur	Early Start	Early Finish
MILESTONES				
GENERAL				
10	Record of Decision	0		30JUN99*
20	Site Selection	0		30SEP99*
30	Primary Contractor Selection	0		30APR00*
35	DOE Design Review	0		31DEC00
40	Authorize Construction	0		31MAR01
50	PSAR	0		30NOV00*
45	Select Construction Contractor	0		31OCT01
55	FSAR Approved by DOE	0		31OCT03*
60	End of Construction	0		31JUL04*
65	DOE Design/Operation Reviews	0		31OCT04*
70	Start-up & Full Operations	0		31JAN05*
PROJECT MANAGEMENT				
GENERAL				
100	Project Definition	9	01MAY99	31JAN00
105	DOE Procurement Action	9	01AUG99	30APR00
110	Site-Specific EIS	18	01NOV99	30APR01
120	Primary Contrractor Evaluation	3	01FEB00	30APR00
130	Permitting & Licensing	44	01MAY00	31DEC03
DESIGN / ENGINEERING				
GENERAL				
200	Preliminary Design	12	01MAY00	30APR01
400	Detailed Design	24	01NOV00	31OCT02
550	Construction Support	33	01NOV01	31JUL04
PROCUREMENT				
GENERAL				
600	Procurement	33	01MAY01	31JAN04
CONSTRUCTION				
PHASE 1 - PROCESS BUILDING AND SUPPORT BUILDINGS		33	01NOV01	31JUL04
PHASE 2 - STORAGE AREA		24	01MAY02	30APR04

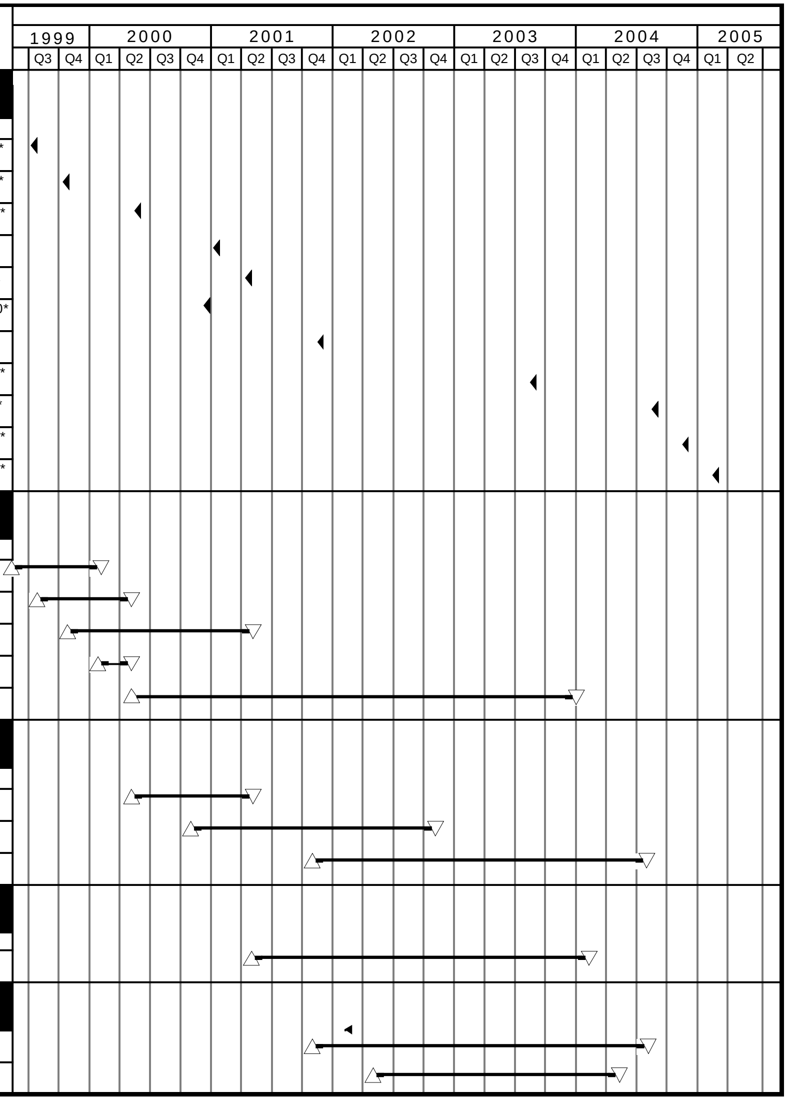


Figure 4.8 U3O8/AHF Plant, 15 Year Privately Owned and Operated Preliminary Project Schedule

Table 4.1 Typical Production Data—25 and 15 Years

	DUF6 to U3O8/AHF	
	25 Years Operations	**15 Years Operations**
Annual Production	18,000 MT DUF6	30,000 MT DUF6
No. cylinders/years	1,476	2,461
Cylinders/day	5.1	8.5
Reaction chambers	4	6
Process Building size	320 x 130 ft	440 x 130 ft
Site area	36 acres	45 acres
Personnel during operations	179 (POPO) 189 (GOCO)	208 (POPO) 218 (GOCO)
U3O8	14,352 MT/yr	23,920 MT/yr
AHF	5,962 MT/yr	9,936 MT/yr
CaF2	269 MT/yr	449 MT/yr

Table 4.2 Comparison of DUF6 Plant Cost Estimates
(in million FY2000 dollars)

	U3O8/AHF 25 Years POPO	**U3O8/AHF 15 Years POPO**	**U3O8/AHF 25 Years GOCO**	**U3O8/AHF 15 Years GOCO**
Facility Capital Cost	197	274	222	309
Annual O&M Cost	26	33	28	35
Total Operating Cost	672	510	717	541
Decon & Decommissioning	20	27	22	31
NEPA/Licensing	5	5	5	5
Lifecycle Cost	**894**	**816**	**966**	**886**
Byproduct Sale Revenue	229	229	229	229
Construction Loan Interest	179	240	-	-
Total Funding Outlay	**845**	**827**	**738**	**657**

Notes: Capital cost includes facility design and construction costs
Total operating cost includes startup and O&M costs over plant operating years
Revenue assumes 70¢/lb from AHF sales
Construction loan assumes @8.5% interest and 10 years payback time for privately owned cases
Funding outlay in POPO cases is payment to cover break-even cost only, no profits included.

Table 4.3 Typical Manpower Loading of a GOCO and POPO Facility

	25 years U308/AHF GOCO	25 years U308/AHF POPO	15 years U308/AHF GOCO	15 years U308/AHF POPO
Officials and Managers	6	6	6	6
Professionals	10	10	10	10
Technicians	16	16	16	16
Office and Clericals	12	10	12	10
Craft workers (Maint.)	24	24	32	32
Operators	80	80	100	100
Line Supervisor	17	17	18	18
Security	24	16	24	16
Total FTEs	189	179	218	208

Table 4.4a U3O8/AHF Project Capital Cost Estimate
Government Owned and Contractor Operated Plant

Facility/Cost Items	15-year Operation	25-year Operation
Process Equipment	59,814,000	41,839,000
Process Facilities	141,522,000	101,017,000
Balance of Plant	60,497,000	45,566,000
Subtotal	**261,833,000**	**188,422,000**
Engineering and Design @ 18%	47,130,000	33,916,000
Total	**308,963,000**	**222,338,000**

Table 4.4b U3O8/AHF Project Capital Cost Estimate
Privately Owned and Privately Operated Plant

Facility/Cost Items	15-year Operation	25-year Operation
Process Equipment	55,526,000	38,815,000
Process Facilities	128,943,000	92,036,000
Balance of Plant	55,104,000	41,523,000
Subtotal	**239,573,000**	**172,374,000**
Engineering and Design @ 14.4%	34,498,000	24,822,000
Total	**274,071,000**	**197,196,000**

Table 4.5a Operation and Maintenance Cost Estimate
Government Owned and Contractor Operated Plant

DESCRIPTION	TOTAL ANNUAL COST 15-Year Operation ($)	TOTAL ANNUAL COST 25-Year Operation ($)
1. Consumable and Materials		
Process Chemicals	117,146	70,218
Cooling Tower Water Treatment Chemicals	42,400	38,160
Product and Waste Containers	5,606,581	3,373,326
Scheduled Replaceable Equipment for Reaction Chambers	949,760	771,680
Facility Maintenance	815,831	607,101
Equipment Spares	1,196,280	836,780
Total Materials	**8,727,998**	**5,697,265**
2. Utilities & Service		
Total Utilities	**2,176,906**	**1,887,114**
3. Labor		
Plant operation labors	19,436,658	16,849,236
Off-site overhead labor	2,332,399	2,021,908
Total Labor	**21,769,057**	**18,871,144**
4. Waste Management & Disposal		
Low Level Wastes	1,766,300	1,169,600
Mixed Low Level Wastes	4,100	4,100
Hazardous Wastes	5,180	5,180
Total Waste Management/Disposal	**1,775,580**	**1,178,880**
Subtotal Operation & Maintenance Annual Cost	**34,449,541**	**27,634,403**
M&O Contractor Fees (2%)	688,991	552,688
Total Operation & Maintenance Annual Cost	**35,138,532**	**28,187,091**
Start-Up Cost Facility start-up cost based on allowance of 65% of one year O&M total labor cost.	**14,149,887**	**12,266,244**
Total O&M Cost for 15 years	**541,227,860**	**716,943,520**

Table 4.5b Operation and Maintenance Cost Estimate
Privately Owned and Privately Operated Plant

DESCRIPTION	TOTAL ANNUAL COST 15-Year Operation ($)	TOTAL ANNUAL COST 25-year Operation ($)
1. Consumable and Materials		
Process Chemicals	117,146	70,218
Cooling Tower Water Treatment Chemicals	42,400	38,160
Product and Waste Containers	5,606,581	3,373,326
Scheduled Replaceable Equipment for Reaction Chambers	949,760	771,680
Facility Maintenance	761,957	566,563
Equipment Spares	1,110,520	776,300
Total Materials	**8,588,360**	**5,596,246**
2. Utilities & Service		
Total Utilities	**2,066,971**	**1,784,126**
3. Labor		
Plant operation labors	18,455,094	15,929,696
Off-site overhead labor	2,214,611	1,911,564
Total Labor	**20,669,705**	**17,841,260**
4. Waste Management & Disposal		
Low Level Wastes	1,766,300	1,169,600
Mixed Low Level Wastes	4,100	4,100
Hazardous Wastes	5,180	5,180
Total Waste Management/Disposal	**1,775,580**	**1,178,880**
Total Operation & Maintenance Annual Cost	**33,100,616**	**26,400,512**
Start-Up Cost Facility start-up cost based on allowance of 65% of one year O&M total labor cost.	**13,435,308**	**11,596,819**
Total O&M Cost for 25 years	**509,944,548**	**671,609,619**

Table 4.6 Expenditure Cost Funding Profile
(GOCO 15 Year Operation)
(in million FY2000 dollars)

	TOTAL	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09
NEPA/Licensing	5.0		0.5	1.2	1.2	1.2	0.9					
Engineering	47.1		1.4	11.8	19.8	10.4	3.1	0.7				
Construction	261.8	0.2	1.9	3.0	25.2	102.2	117.2	12.1				
Total Capital Cost:	314.0	0.2	3.8	16.0	46.2	113.8	121.2	12.8				
Startup	14.2							14.2				
Operations	527.1							8.8	35.1	35.1	35.1	35.1
Decon &Decommission	30.9											
Total Operation Cost:	572.1							22.9	35.1	35.1	35.1	35.1
Revenue from Chemical Sale:	228.6							3.8	15.2	15.2	15.2	15.2
Total Budget Outlay:	657.5	0.2	3.8	16.0	46.2	113.8	121.2	31.9	19.9	19.9	19.9	19.9

Assumption:

Chemical Sale Price: 70 ¢/lb of HF

Table 4.6, continued Expenditure Cost Funding Profile
(GOCO 15 Year Operation)
(in million FY2000 dollars)

	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
NEPA/Licensing													
Engineering													
Construction													
Total Capital Cost:													
Startup													
Operations	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	26.4		
Decon &Decommission												15.4	15.4
Total Operation Cost:	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	26.4	15.4	15.4
Revenue from Chemical Sale:	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	11.4		
Total Budget Outlay:	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	14.9	15.4	15.4

Table 4.7 Expenditure Cost Funding Profile
(GOCO 25 Year Operation)
(in million FY2000 dollars)

	TOTAL	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09
NEPA/Licensing	5.0		0.5	1.2	1.2	1.2	0.9					
Engineering	33.9		1.1	8.6	14.3	7.8	2.1					
Construction	188.4	0.1	1.4	2.2	28.8	90.3	65.6					
Total Capital Cost:	227.3	0.1	3.0	12.0	44.2	99.3	68.6					
Startup	12.3						6.1	6.1				
Operations	704.7							21.1	28.2	28.2	28.2	28.2
Decon &Decommission	22.2											
Total Operation Cost:	739.2						6.1	27.3	28.2	28.2	28.2	28.2
Revenue from Chemical Sale:	228.6							6.9	9.1	9.1	9.1	9.1
Total Budget Outlay:	737.9	0.1	3.0	12.0	44.2	99.3	74.8	20.4	19.0	19.0	19.0	19.0

Assumption:

Chemical Sale Price: 70 ¢/lb of HF

Table 4.7, continued Expenditure Cost Funding Profile (GOCO 25 Year Operation) (in million FY2000 dollars)

	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
NEPA/Licensing													
Engineering													
Construction													
Total Capital Cost:													
Startup													
Operations	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2
Decon &Decommission													
Total Operation Cost:	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2
Revenue from Chemical Sale:	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Total Budget Outlay:	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0

Table 4.7, continued Expenditure Cost Funding Profile
(GOCO 25 Year Operation)
(in million FY2000 dollars)

	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32
NEPA/Licensing										
Engineering										
Construction										
Total Capital Cost:										
Startup										
Operations	28.2	28.2	28.2	28.2	28.2	28.2	28.2	7.0		
Decon &Decommission									11.1	11.1
Total Operation Cost:	28.2	28.2	28.2	28.2	28.2	28.2	28.2	7.0	11.1	11.1
Revenue from Chemical Sale:	9.1	9.1	9.1	9.1	9.1	9.1	9.1	2.3		
Total Budget Outlay:	19.0	19.0	19.0	19.0	19.0	19.0	19.0	4.8	11.1	11.1

Table 4.8 Expenditure Funding Profile
(POPO 15 Year Operation)
10-year payback
(in million FY2000 dollars)

	TOTAL	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09
Construction Investment:												
NEPA/Licensing	5.0		0.5	1.3	1.3	1.3	0.6					
Engineering	34.5		4.3	15.9	10.7	3.2	0.5					
Construction	239.6	0.2	2.3	7.4	43.0	108.6	78.0					
Start-up	13.4						13.4					
Total Investment Loan	292.5	0.2	7.1	24.6	55.0	113.1	92.5					
Accumulated Debt:		0.3	8.0	35.3	98.0	229.0	348.9	325.3	299.8	272.2	242.1	209.5
Operation Expenses:												
Debt Payment	531.7							53.2	53.2	53.2	53.2	53.2
Operation & Maintenance	496.5							22.1	33.1	33.1	33.1	33.1
Decon &Decommission	27.4											
Total Operation Expenses	1055.6							75.2	86.3	86.3	86.3	86.3
Revenues:												
Break-even Conversion Revenue	827.0							49.4	74.0	74.0	74.0	74.0
HF Product Sales	228.6							10.2	15.2	15.2	15.2	15.2
Total Revenue	1055.6							59.5	89.3	89.3	89.3	89.3
Cash Funding Requirements:	587.8	0.2	7.1	24.6	55.0	113.1	92.5	11.9	17.9	17.9	17.9	17.9
Break-even Government Payment:	827.0							49.4	74.0	74.0	74.0	74.0

Notes: Cash funding requirements reflect cash flow required for construction and operating minus revenue from AHF sales. Break-even government payment is the funding from DOE paid to the private plant owner for the conversion service to cover the break-even cost for construction loan payment, operation, and D&D only; no profits included.

Assumptions:

Loan Interest Rate @ 8.5% for Construction Loan during construction period
Loan Interest Rate @ 8.5% for payback in 10 years at start of operation

Chemical Sale Price: 70 ¢/lb of HF

Table 4.8, continued Expenditure Funding Profile
(POPO 15 Year Operation)
10-year payback
(in million FY2000 dollars)

	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
Construction Investment:													
NEPA/Licensing													
Engineering													
Construction													
Start-up													
Total Investment Loan													
Accumulated Debt:	174.2	135.8	94.2	49.0	0.0								
Operation Expenses:													
Debt Payment	53.2	53.2	53.2	53.2	53.2								
Operation & Maintenance	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	11.0		
Decon &Decommission												13.7	13.7
Total Operation Expenses	86.3	86.3	86.3	86.3	86.3	33.1	33.1	33.1	33.1	33.1	11.0	13.7	13.7
Revenues:													
Break-even Conversion Revenue	74.0	74.0	74.0	74.0	74.0	20.9	20.9	20.9	20.9	20.9	7.0		
HF Product Sales	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	5.1		
Total Revenue	89.3	89.3	89.3	89.3	89.3	36.1	36.1	36.1	36.1	36.1	12.0		
Cash Funding Requirements:	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	6.0	13.7	13.7
Break-even Government Payment:	74.0	74.0	74.0	74.0	74.0	20.9	20.9	20.9	20.9	20.9	7.0		

Table 4.9 Expenditure Funding Profile
U3O8/AHF (POPO 25 Year Operation)
10-year payback
(in million FY2000 dollars)

	TOTAL	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09
Construction Investment:												
NEPA/Licensing	5.0		0.5	1.3	1.3	1.3	0.5					
Engineering	24.8		3.1	11.5	7.7	2.3	0.3					
Construction	172.4	0.2	1.7	4.5	31.5	102.9	31.6					
Start-up	12.6						12.6					
Total Investment Loan	214.8	0.2	5.2	17.3	40.5	106.5	45.0					
Accumulated Debt:		0.2	5.9	25.2	71.3	192.9	258.2	240.8	221.9	201.4	179.2	155.1
Operation Expenses:												
Debt Payment	393.5							39.3	39.3	39.3	39.3	39.3
Operation & Maintenance	660.0						4.4	26.4	26.4	26.4	26.4	26.4
Decon &Decommission	19.7											
Total Operation Expenses	1073.2						4.4	65.7	65.7	65.7	65.7	65.7
Revenues:												
Break-even Conversion Revenue	844.6						9.5	57.1	57.1	57.1	57.1	57.1
HF Product Sales	228.6						1.5	9.1	9.1	9.1	9.1	9.1
Total Revenue	1073.2						11.0	66.3	66.3	66.3	66.3	66.3
Cash Funding Requirements:	665.9	0.2	5.2	17.3	40.5	106.5	47.9	17.3	17.3	17.3	17.3	17.3
Break-even Government Payment:	844.6						9.5	57.1	57.1	57.1	57.1	57.1

Notes: Cash funding requirements reflect cash flow required for construction and operating minus revenue from AHF sales. Break-even government payment is the funding from DOE paid to the private plant owner for the conversion service to cover the break-even cost for construction loan payment, operation, and D&D only; no profits included.

Assumptions:

Loan Interest Rate @ 8.5% for Construction Loan during construction period
Loan Interest Rate @ 8.5% for payback in 10 years at start of operation

Chemical Sale Price: 70 ¢/lb of HF

Table 4.9, continued Expenditure Funding Profile
U3O8/AHF (POPO 25 Year Operation)
10-year payback
(in million FY2000 dollars)

	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
Construction Investment:													
NEPA/Licensing													
Engineering													
Construction													
Start-up													
Total Investment Loan													
Accumulated Debt:	128.9	100.5	69.7	36.3	0.0								
Operation Expenses:													
Debt Payment	39.3	39.3	39.3	39.3	39.3								
Operation & Maintenance	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4
Decon &Decommission													
Total Operation Expenses	65.7	65.7	65.7	65.7	65.7	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4
Revenues:													
Break-even Conversion Revenue	57.1	57.1	57.1	57.1	57.1	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8
HF Product Sales	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Total Revenue	66.3	66.3	66.3	66.3	66.3	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9
Cash Funding Requirements:	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3
Break-even Government Payment:	57.1	57.1	57.1	57.1	57.1	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8

Table 4.9, continued Expenditure Funding Profile
U3O8/AHF (POPO 25 Year Operation)
10-year payback
(in million FY2000 dollars)

	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32
Construction Investment:										
NEPA/Licensing										
Engineering										
Construction										
Start-up										
Total Investment Loan										
Accumulated Debt:										
Operation Expenses:										
Debt Payment										
Operation & Maintenance	26.4	26.4	26.4	26.4	26.4	26.4	22.0			
Decon &Decommission								9.9	9.9	
Total Operation Expenses	26.4	26.4	26.4	26.4	26.4	26.4	22.0	9.9	9.9	
Revenues:										
Break-even Conversion Revenue	17.8	17.8	17.8	17.8	17.8	17.8	14.8			
HF Product Sales	9.1	9.1	9.1	9.1	9.1	9.1	7.6			
Total Revenue	26.9	26.9	26.9	26.9	26.9	26.9	22.4			
Cash Funding Requirements:	17.3	17.3	17.3	17.3	17.3	17.3	14.4	9.9	9.9	
Break-even Government Payment:	17.8	17.8	17.8	17.8	17.8	17.8	14.8			

Table 4.10 Expenditure Funding Profile
U3O8/AHF (POPO 15 Year Operation)
5-year payback
(in million FY2000 dollars)

	TOTAL	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09
Construction Investment:												
NEPA/Licensing	5.0		0.5	1.3	1.3	1.3	0.6					
Engineering	34.5		4.3	15.9	10.7	3.2	0.5					
Construction	239.6	0.2	2.3	7.4	43.0	108.6	78.0					
Start-up	13.4						13.4					
Total Investment Loan	292.5	0.2	7.1	24.6	55.0	113.1	92.5					
Accumulated Debt:		0.3	8.0	35.3	98.0	229.0	348.9	290.0	226.1	156.8	81.6	0.0
Operation Expenses:												
Debt Payment	442.7							88.5	88.5	88.5	88.5	88.5
Operation & Maintenance	496.5							22.1	33.1	33.1	33.1	33.1
Decon &Decommission	27.4											
Total Operation Expenses	966.6							110.6	121.6	121.6	121.6	121.6
Revenues:												
Break-even Conversion Revenue	738.0							73.5	110.2	110.2	110.2	110.2
HF Product Sales	228.6							10.2	15.2	15.2	15.2	15.2
Total Revenue	966.6							83.6	125.4	125.4	125.4	125.4
Cash Funding Requirements:	587.8	0.2	7.1	24.6	55.0	113.1	92.5	11.9	17.9	17.9	17.9	17.9
Break-even Government Payment:	738.0							73.5	110.2	110.2	110.2	110.2

Notes: Cash funding requirements reflect cash flow required for construction and operating minus revenue from AHF sales. Break-even government payment is the funding from DOE paid to the private plant owner for the conversion service to cover the break-even cost for construction loan payment, operation and D&D; no profits included.

Assumptions:

Loan Interest Rate @ 8.5% for Construction Loan during construction period
Loan Interest Rate @ 8.5% for payback in 5 years at start of operation

Chemical Sale Price: 70 ¢/lb of HF

Table 4.10, continued Expenditure Funding Profile
U3O8/AHF (POPO 15 Year Operation)
5-year payback
(in million FY2000 dollars)

	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
Construction Investment:													
NEPA/Licensing													
Engineering													
Construction													
Start-up													
Total Investment Loan													
Accumulated Debt:													
Operation Expenses:													
Debt Payment													
Operation & Maintenance	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	11.0		
Decon &Decommission												13.7	13.7
Total Operation Expenses	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	11.0	13.7	13.7
Revenues:													
Break-even Conversion Revenue	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	7.2		
HF Product Sales	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	5.1		
Total Revenue	36.9	36.9	36.9	36.9	36.9	36.9	36.9	36.9	36.9	36.9	12.3		
Cash Funding Requirements:	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	6.0	13.7	13.7
Break-even Government Payment:	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	7.2		

Table 4.11 Expenditure Funding Profile
U3O8/AHF (POPO 25 Year Operation)
5-year payback
(in million FY2000 dollars)

	TOTAL	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09
Construction Investment:												
NEPA/Licensing	5.0		0.5	1.3	1.3	1.3	0.5					
Engineering	24.8		3.1	11.5	7.7	2.3	0.3					
Construction	172.4	0.2	1.7	4.5	31.5	102.9	31.6					
Start-up	12.6						12.6					
Total Investment Loan	214.8	0.2	5.2	17.3	40.5	106.5	45.0					
Accumulated Debt:		0.2	5.9	25.2	71.3	192.9	258.2	214.6	167.3	116.0	60.4	0.0
Operation Expenses:												
Debt Payment	327.6							65.5	65.5	65.5	65.5	65.5
Operation & Maintenance	660.0						4.4	26.4	26.4	26.4	26.4	26.4
Decon &Decommission	19.7											
Total Operation Expenses	1007.3						4.4	91.9	91.9	91.9	91.9	91.9
Revenues:												
Break-even Conversion Revenue	778.7						13.9	83.1	83.1	83.1	83.1	83.1
HF Product Sales	228.6						1.5	9.1	9.1	9.1	9.1	9.1
Total Revenue	1007.3						15.4	92.3	92.3	92.3	92.3	92.3
Cash Funding Requirements:	665.9	0.2	5.2	17.3	40.5	106.5	47.9	17.3	17.3	17.3	17.3	17.3
Break-even Government Payment:	778.7						13.9	83.1	83.1	83.1	83.1	83.1

Table 4.11, continued Expenditure Funding Profile
U3O8/AHF (POPO 25 Year Operation)
5-year payback
(in million FY2000 dollars)

	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
Construction Investment:													
NEPA/Licensing													
Engineering													
Construction													
Start-up													
Total Investment Loan													
Accumulated Debt:													
Operation Expenses:													
Debt Payment													
Operation & Maintenance	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4
Decon &Decommission													
Total Operation Expenses	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4	26.4
Revenues:													
Break-even Conversion Revenue	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6
HF Product Sales	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Total Revenue	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7
Cash Funding Requirements:	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3
Break-even Government Payment:	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6

Table 4.11, continued Expenditure Funding Profile
U3O8/AHF (POPO 25 Year Operation)
5-year payback
(in million FY2000 dollars)

	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32
Construction Investment:										
NEPA/Licensing										
Engineering										
Construction										
Start-up										
Total Investment Loan										
Accumulated Debt:										
Operation Expenses:										
Debt Payment										
Operation & Maintenance	26.4	26.4	26.4	26.4	26.4	26.4	22.0			
Decon &Decommission								9.9	9.9	
Total Operation Expenses	26.4	26.4	26.4	26.4	26.4	26.4	22.0	9.9	9.9	
Revenues:										
Break-even Conversion Revenue	17.6	17.6	17.6	17.6	17.6	17.6	14.7			
HF Product Sales	9.1	9.1	9.1	9.1	9.1	9.1	7.6			
Total Revenue	26.7	26.7	26.7	26.7	26.7	26.7	22.3			
Cash Funding Requirements:	17.3	17.3	17.3	17.3	17.3	17.3	14.4	9.9	9.9	
Break-even Government Payment:	17.6	17.6	17.6	17.6	17.6	17.6	14.7			

5. DUF6 Conversion to U3O8/AHF/CaF2

5.1 Introduction

About 700,000 metric tons (MT) of depleted uranium hexafluoride (DUF6) are currently stored at the Paducah, Portsmouth and Oak Ridge sites. Public Law 105-204 requires the DOE to submit to Congress a plan to ensure that all funds accrued on the books of USEC for disposition of DUF6 will be used for the construction and operation of plants to treat and recycle the DUF6. The Department of Energy's Initial Plan calls for construction to begin in the year 2002 time frame.

This report section examines the costs and issues for plant construction based on a conversion plant using a dry process to convert DUF6 to uranium oxide (U3O8), anhydrous hydrogen fluoride (AHF) and calcium fluoride (CaF2) as final products. The plant has two operating modes: 100% production of AHF only or 100% production of only CaF2 . The construction and operation of the conversion plant is based on private ownership and operation with DOE regulations and operating for 25 years.

A preconceptual plant design, rough cost estimate, and preliminary project schedule were developed. The conversion plant includes capabilities for DUF6 cylinder preparation, conversion of DUF6 to uranium oxide and fluorine byproducts, empty cylinder treatment for disposal, and interim storage for oxide and byproducts.

Significant design bases for the conversion plant include:

- The plant will convert DUF6 to U3O8 by a dry process. Hydrogen fluoride (HF) off-gas will be treated to produce AHF and a minor quantity of calcium fluoride (CaF2). Capability to treat the HF off-gas to produce calcium fluoride only (and no AHF) is also provided.

- The plant capacity will be based on a 25 year operating period to process a DUF6 inventory of 36,910 cylinders (450,000 MT DUF6) over the life of the plant.

- Storage will be provided for one year production of U3O8 and CaF2 product and two months production of AHF.

- The AHF product is available for sale by plant owner to commercial users. The U3O8 and CaF2 products are returned to the DOE.

- To bound costs associated with empty cylinders, assume all empty cylinders will be washed, compacted, and returned to the DOE for disposal.

- The plant will be located on a DOE owned site at or near a gaseous diffusion plant and include the support facilities and infrastructures/utilities needed for a greenfield facility.

- The design will consider addition of future process and storage buildings.

5.2 Summary of Results

The plant annually processes 18,000 MT of DUF6 contained in 1,476 cylinders to produce 14,352 MT of U3O8 and 2,000 MT of empty cylinder metal waste. The plant produces 5,962 MT of AHF and 269 MT of CaF2 in the AHF mode, or 11,966 MT of CaF2 and no AHF in the CaF2 mode. The plant, which includes a one year storage capacity for U3O8 and CaF2 and two months storage capacity for AHF, occupies about 39 acres. Additional storage capacity would require about 5 acres for each year of additional U_3O_8 or CaF_2 storage.

The construction capital cost estimate is $202 million for the plant facilities. The engineering cost is about $29 million. Each year of additional storage would be $20 million for U_3O_8 and $16 million for CaF_2. These costs are in 1st Quarter FY2000 dollars.

The annual operation and maintenance (O&M) cost is about $27 million in the AHF production mode and $30 million in the CaF_2 production mode. The O&M cost does not include disposal of empty cylinder metal. Cost for NEPA, regulatory and licensing activities is estimated at $5 million. Decontamination and decommissioning (D&D) cost is estimated at $23 million.

The preliminary schedule assumes selection of a private plant contractor in April 2000. The schedule shows plant engineering design starting in May 2000, construction beginning in November 2001, plant completion in January 2004, and full operation beginning in July 2004. Peak engineering personnel is 80 persons and peak employment during construction is about 480 persons. Plant employment during operations is 183 persons.

The 2002 construction start depends on the key milestone dates for site selection, selection of primary contractor and construction contractor, and construction approval. The schedule includes NEPA activities, as a site-specific EIS will be required, and DOE regulatory activities. The amount of U_3O_8 storage provided affects cost and may need additional study. Process design criteria for DUF_6 cylinder vaporization, conversion reaction chamber, HF distillation, and empty cylinder treatment are necessary to ensure successful facility design and operation.

5.3 Conversion Process Description

Depleted uranium hexafluoride (DUF_6) is processed to produce U_3O_8, AHF and CaF_2. The average throughput is 5 cylinders per day (5,670 lb/hr DUF_6) based on 80% plant availability (7,000 hours/yr or 292 days/yr). The process block flow diagram for AHF production is shown in Figure 5.1. The diagram for CaF_2 production is shown in Figure 5.2.

The plant is designed to produce AHF or CaF_2, but not both simultaneously. Production would be shut down during the transition between the AHF and CaF_2 production modes. The desired mix of AHF and CaF_2 product is obtained by campaigning operations. Much of the equipment is common and would be used during both production modes.

The DUF_6 is shipped by truck from the cylinder yards at the gaseous diffusion plant to an outdoor storage pad at the Conversion Facility. The cylinder is moved into the Process Building for inspection and preparation. The cylinders are loaded into steam-heated autoclaves to vaporize the DUF_6 for feeding into the conversion process. Cylinders with questionable integrity are loaded into hot air ovens where the solid DUF_6 sublimes into a gas under vacuum. This avoids melting the UF_6 and pressurizing the cylinder, which occurs when using an autoclave. Several of the cylinders may be substandard based on the DUF_6 Engineering Analysis Report (p. 6.1-4-5).

After vaporization, the empty cylinders are transferred to an outdoor pad and stored for three months. This allows for radioactive decay of non-volatile daughter products in the cylinder. The cylinders are then brought into the Process Building, washed with water, crushed, and loaded into boxes. Each 6x14x3 ft high box contains about 9,000 lb of metal from three crushed cylinders. The filled boxes are stored in the Waste Storage Building and transported to the gaseous diffusion plant for disposition. The cylinder wash effluents are fed into the main conversion processes.

5.3.1 Anhydrous HF Production Mode

The DUF6 gas is converted to U3O8 in a series of two reaction chambers, where it is mixed with an HF/water vapor mixture in the first chamber and with steam in the second chamber. The chemical reactions are:

$UF6 + 2\ H_2O \text{ ---> } UO2F_2 + 4\ HF$

$3\ UO2F_2 + 3\ H_2O \text{ ---> } U3O8 + 6\ HF + 0.5\ O_2$

Four reaction lines are provided to meet the required throughput. The U3O8 product is cooled, compacted to increase its bulk density, and packaged in metal bins. The 100 cu ft bins are about 4x4x7 ft high and hold 9 tons (8.16 MT) of U3O8. The filled bins are transferred to the U3O8 Storage Building.

Reaction chamber off-gas containing HF, steam and oxygen is filtered to remove uranium particulates. The off-gas then flows to the HF distillation system, which concentrates the mixture to produce anhydrous HF in the overhead product. The AHF is collected, sampled, and pumped to large storage tanks in the HF Storage Building, where the AHF is loaded into railcars or tank trucks for delivery to customers. The AHF is expected to contain less than 1 ppm uranium.

The aqueous hydrogen fluoride bottoms stream from HF distillation is collected, vaporized and recycled to the first reaction chamber. To prevent the buildup of impurities in the recycle stream, a small fraction is withdrawn. This purge stream is neutralized with hydrated lime, mixed with cement and water to form a grout, and packaged in drums for disposal.

Off-gas from the distillation column, primarily oxygen and air inleakage, flows to the scrubber system. Residual HF in the off-gas is removed by scrubbing with a potassium hydroxide (KOH) solution. The off-gas is then HEPA-filtered and discharged to the atmosphere. The spent scrub solution is regenerated with hydrated lime ($Ca(OH)_2$), which produces a calcium fluoride (CaF2) byproduct. The chemical reactions are:

$HF + KOH \text{ ---> } KF + H_2O$

$2\ KF + Ca(OH)_2 \text{ ---> } CaF2 + 2\ KOH$

The CaF2 is separated by filtering, washed with water, dried and loaded into drums. The drums, containing 700 lb of CaF2, are transferred to the CaF2 Storage Building. The CaF2 is expected to contain less than 1 ppm uranium.

5.3.2 Calcium Fluoride Production Mode

The DUF6 gas is converted to U3O8 in a series of two reaction chambers, where it is mixed with steam and nitrogen in the first chamber and steam and hydrogen in the second chamber. The chemical reactions are:

$UF6 + 2\ H_2O \text{ ---> } UO2F_2 + 4\ HF$

$3\ UO2F_2 + 3\ H_2O \text{ ---> } U3O8 + 6\ HF + 0.5\ O_2$

$H_2 + 0.5\ O_2 \text{ ---> } H_2O$

The U3O8 product is cooled, compacted to increase its bulk density, packaged in metal bins, and transferred to the U3O8 Storage Building. Reaction chamber off-gas containing HF, excess steam, and nitrogen is filtered to remove uranium particulates. The reaction chambers, filters and U3O8 handling equipment are the same ones used in the AHF production mode.

After filtration, the reaction off-gas flows to the HF absorption columns, where the HF and steam are contacted with a liquid solution and condensed. Off-gas from the absorption columns then flows to the same scrubber system described above. The aqueous HF solution that is produced from absorption is transferred to neutralization tanks and neutralized with slaked lime according to the reaction:

$2\ HF + Ca(OH)_2 \text{ ---> } CaF2 + 2\ H_2O$

The resulting CaF2 precipitate is separated by filtering, washed with water, dried and loaded into bins. The 100 cu ft bins are about 4x4x7 ft high and hold 5 tons (4.54 MT) of CaF2. The filled bins are transferred to the CaF2 Storage Building. The CaF2 is expected to contain less than 1 ppm uranium.

5.3.3 Major Feeds and Products, and Process Equipment

Major process materials and annual quantities are summarized below:

Major Input Streams	**Major Output Streams**
Depleted Uranium Hexafluoride 18,000 MT/yr 1476 cylinders/yr	Uranium Oxide (U3O8) 14,352 MT/yr 1,758 4x4x7 ft H bins/yr (18,000 lb/bin) or 24,344 55-gal drums/yr (1300 lb/drum)
Lime (CaO) <u>CaF2 Production Mode only</u> 8,505 MT/yr 312,600 ft3/yr	Anhydrous Hydrogen Fluoride (HF) <u>AHF Production Mode only</u> 5,962 MT/yr 1.64 million gal/yr
Hydrated Lime Ca(OH)2 <u>AHF Production Mode</u> 325 MT/yr 8,700 ft3/yr <u>CaF2 Production Mode</u> 113 MT/yr 3,000 ft3/yr	Calcium Fluoride (CaF2) <u>AHF Production Mode</u> 269 MT/yr 848 55-gal drums/yr (700 lb/drum) <u>CaF2 Production Mode</u> 11,966 MT/yr 2,639 4x4x7(h) ft bins/yr (10,000 lb/bin)
Cement <u>AHF Production Mode only</u> 154 MT/yr 2,900 ft3/yr	Empty Cylinder Metal Waste 2000 MT/yr 492 6x14x3(h) ft boxes/yr (9,000 lb/box)
Ammonia (NH3) <u>CaF2 Production Mode only</u> 193 MT/yr 84,000 gal/yr	Grouted Waste <u>AHF Production Mode only</u> 367 MT/yr 1,012 55-gal drums/yr (800 lb/drum)

Major process equipment used in both the AHF and CaF2 production modes includes four steam autoclaves, six hot air ovens, four reaction chamber lines, U3O8 compacting and bin loading system, off-gas scrubbing system, two empty cylinder washing machines and one cylinder crusher. Major equipment used for AHF production only includes the HF distillation system and neutralization/grouting system. Equipment for CaF2 production only includes the HF absorption and neutralization system, and calcium fluoride drying and packaging system.

5.4 Conversion Plant Description

The Conversion Facility is assumed to be constructed on a DOE site at a greenfield location at or near a gaseous diffusion plant. The Conversion Facility occupies about 39 acres. Additional storage buildings for U3O8 and CaF2 could be built adjacent or at a nearby location. Each additional one year increment of U3O8 or CaF2 storage occupies about 5 acres. A conceptual site plan for the Conversion Facility is shown in Figure 5.3.

The Conversion Facility includes full and empty cylinder storage pads, the Process Building, a U3O8 Storage Building, an HF Storage Building, a CaF2 Storage Building, a Waste Storage Building and support facilities. The site plan considers addition of future process facilities such as uranium metal or sintered uranium pellets.

The Conversion Facility will be designed and constructed in compliance with DOE Orders and applicable regulations and codes, and will meet the intent of NRC standards. In general, a graded approach as established in DOE Order 420.1 is used for the design of all structures, systems, and components (SSC) in the plant facilities. All SSC's will be assigned a Natural Phenomena Performance Category using the criteria in the DOE Standards DOE-STD-1020-94 and DOE-STD-1021-93 during the design phase.

In the absence of a hazard analysis, it is assumed that the Process Building is performance category PC-3 to control and confine hazardous material. The building structure is reinforced concrete construction in the processing areas. The remainder of the building housing the personnel support area is steel frame, metal siding construction. The Process Building is 30 ft high in the processing areas and 18 ft high in the support areas. HVAC equipment is located on a mezzanine level. The process room air is filtered through one stage of HEPA filters prior to discharge to atmosphere. The Process Building general arrangement is shown in Figure 5.4.

The U3O8 Storage Building and CaF2 Storage Building have a one year capacity. The U3O8 Building holds 1,760 bins stacked one high, and the CaF2 Building holds 2,640 bins stacked two high. The Waste Storage Building has a one month capacity for staging treated empty cylinders and process waste for transport offsite. The U3O8, CaF2, and Waste Storage Buildings are assumed PC-2 to maintain storage function after the occurrence of a natural phenomena hazards event. These buildings are steel frame and concrete clad panel construction. They are ventilated and lighted, but no heating, cooling or HEPA filtration is provided. Access aisles allow personnel to inspect the bins during storage. A general storage arrangement for the U3O8 Building is shown in Figure 5.5. A general storage arrangement for the CaF2 Building is shown in Figure 5.6.

The HF Storage Building has a two month capacity with ten 34,000-gallon storage tanks. The HF Storage Building is assumed to be PC-3 to control and confine hazardous material. The building structure is reinforced concrete construction. The HF storage tanks are housed separately in cell rooms.

Plant operations are assumed to be continuous for 24 hours/day, 7 days/week, 52 weeks/year. Due to seven day per week operation, a fourth shift is necessary to account for normal days off for employees. The number of employees during operation is estimated to be 183 persons, with 66 employees on day shift and 39 each of the other three shifts. The numbers are estimated based on process operation labor and facility support labor requirements needed to operate the plant. A breakdown of the plant operation employees by category and by shift is shown in Table 5.1.

5.5 Cost Estimate

The cost estimates are rough order of magnitude estimates based on a preconceptual level design information. The cost estimate results are summarized below:

	Cost ($million)	**Contingency ($million)**	**Total Cost ($million)**
Conversion Facility			
Engineering	--	--	29
Plant Facilities Construction Cost	150	52	202
Startup Cost	--	--	12
Annual Operations and Maintenance Cost (O&M)	--	--	27 (for AHF mode) 30 (for CaF2 mode)
Decontamination and Decommissioning (D&D)	--	--	23
Additional Storage			
Engineering	--	--	3
U3O8 Storage (1 yr capacity) Construction Cost	17	3	20
CaF2 Storage (1 yr capacity) Construction Cost	14	2	16
NEPA/Licensing	--	--	5

The estimates do not include costs for plant design criteria development, cost of land, site qualifications, or extension of local roads and utility lines to the site boundary. The estimates take into account the labor productivity and indirect cost factors for a privately run project. Cost estimate bases are described in the Appendix.

The construction capital costs are based on an engineering, procurement and construction management (EPCM) approach. Capital costs, see Table 5.2, are reported in 1st quarter fiscal year 2000 dollars (October 1999). Labor costs are based on local wage rates at a generic gaseous diffusion plant located in mid-U.S.A. The capital cost estimate utilized historical cost data, estimating manuals, allowances and budgetary quotations. A 35% contingency was applied to the capital costs for the Conversion Facility and 15% for the subsequent Storage Facilities. These contingency levels are based on previous risk analysis on projects of similar scope and level of design details. Engineering cost was estimated at 14.4% of the capital costs for the Conversion Facility and 8% for the subsequent Storage Facilities. The lower percentages are used for the subsequent Storage Facilities because previous building engineering design can be reused. Product and waste container costs are included in the O&M costs. The D&D cost was estimated as 10% of the capital cost.

The O&M cost includes costs for materials, utilities, labor, and waste disposal, see Table 5.3. Plant startup cost was assumed to be 65% of the annual O&M labor cost. The difference in O&M cost for AHF or CaF2 production mode reflects the added cost for CaF2 storage bins in the CaF2 production mode or added cost for process grout waste disposal in the AHF production mode. The annual O&M cost does not include the cost for disposal of empty cylinder metal waste. If the empty cylinder metal is to be disposed as low-level waste (LLW), the estimated disposal cost would range from $1 million to $12 million annually, depending on the disposal sites. Revenue from sales of AHF is also not included in the O&M cost.

The annual expenditure required to support the construction and operation of the conversion plant for the initial years is shown in Table 5.4a and 5.4b. The expenditure profile for all years is shown below. The expenditure profiles are derived from loading the estimated capital and operating costs onto the project schedule. A constant FY2000 dollar value is used in the expenditure outlay because of the difficulty in accurately projecting the inflation rate for future years.

5.6 Project Schedule

An estimated preliminary project schedule is shown in Figure 5.7. The schedule allows 2.5 years for engineering design and 2 years for construction. The schedule is based on a fast track premise with overlapping engineering phases and early procurement of some key equipment (most equipment is available in 12-18 month lead time) and a two-phase construction plan. The estimated peak engineering personnel is 80 persons and peak employment during construction is 480 persons.

5.7 Discussion and Issues

5.7.1 Process

Bins were used to package the U3O8 because of the space savings compared to 55-gallon drums. Using bins instead of drums reduces the storage building area by about 35%. Additional study is needed to determine the best storage container to use with the cost considerations on facilities and transport.

The CaF2 product is not a hazardous waste, but CaF2 powder is a health hazard and containment is required during handling. Packaging the CaF2 in sealed bins is appropriate for long-term storage or transport to customers. Other methods of handling the CaF2 include bulk storage in vaults or silos and shipment in rail hopper cars or tank trucks.

In cylinder washing, the empty cylinders are cleaned to remove the reactive fluoride materials inside the cylinder. It was assumed that the metal from washed empty cylinders is returned to the DOE for disposal. The residual uranium contaminated cylinders might require the cylinder metal to be disposed of as LLW. Alternate dispositions include recycling and reusing the radioactively-contaminated carbon steel for LLW containers for use in the nuclear industry or sufficiently decontaminating the metal for disposal as non-hazardous waste or scrap.

The purity of the calcium oxide (CaO, quicklime) fed to lime slaking and used to neutralize the HF affects the purity of the CaF2 product. Typical high calcium quicklime contains up to 5% impurities (mainly MgO and $CaCO_3$), which could end up in the CaF2 product. If this impurity is objectionable, high purity calcium oxide could be used.

5.7.2 Facility

Buildings for processing and storage were assumed to be performance category PC-2 or PC-3. A safety and accident analysis was not performed is needed to determine the hazard classification and performance category. The appropriate structure, confinement and ventilation for buildings housing large quantities of U3O8 needs study.

The DUF6 Engineering Analysis Report has identified issues with federal (49CFR173.420) or ANSI N14.1 transportation requirements and overpressured, overfilled or substandard cylinders. The Report suggests that a new overpack be designed and licensed if filled substandard cylinders must be shipped from off-site. The cost of overpacks is not considered in the report. This transportation issue still needs to be resolved.

The preconceptual plant design is essentially a single line plant. Multiple autoclaves, ovens, and conversion reaction chambers are provided to obtain the design throughput. The HF distillation system, absorption system, scrubber and neutralization systems are single line systems with installed spares on maintenance-prone items such as pumps and filters. A RAM (reliability, availability, maintainability) analysis may help determine if this configuration is satisfactory and whether independent parallel lines might be desirable.

5.7.3 Cost Estimate

The cost estimate is based on a privately owned and privately operated plant located on a government facility site. The major contributors to the capital cost are the Process Building including the structure and service systems. The major process equipment costs are the cylinder handling crane, autoclaves, hot air ovens and DUF6 compressors, conversion reaction chambers, distillation equipment, and cylinder tilt and roll wash stands. The cost to dispose of empty cylinder metal is not included in this report. If it is disposed as LLW, the disposal cost could be significant.

5.7.4 Schedule

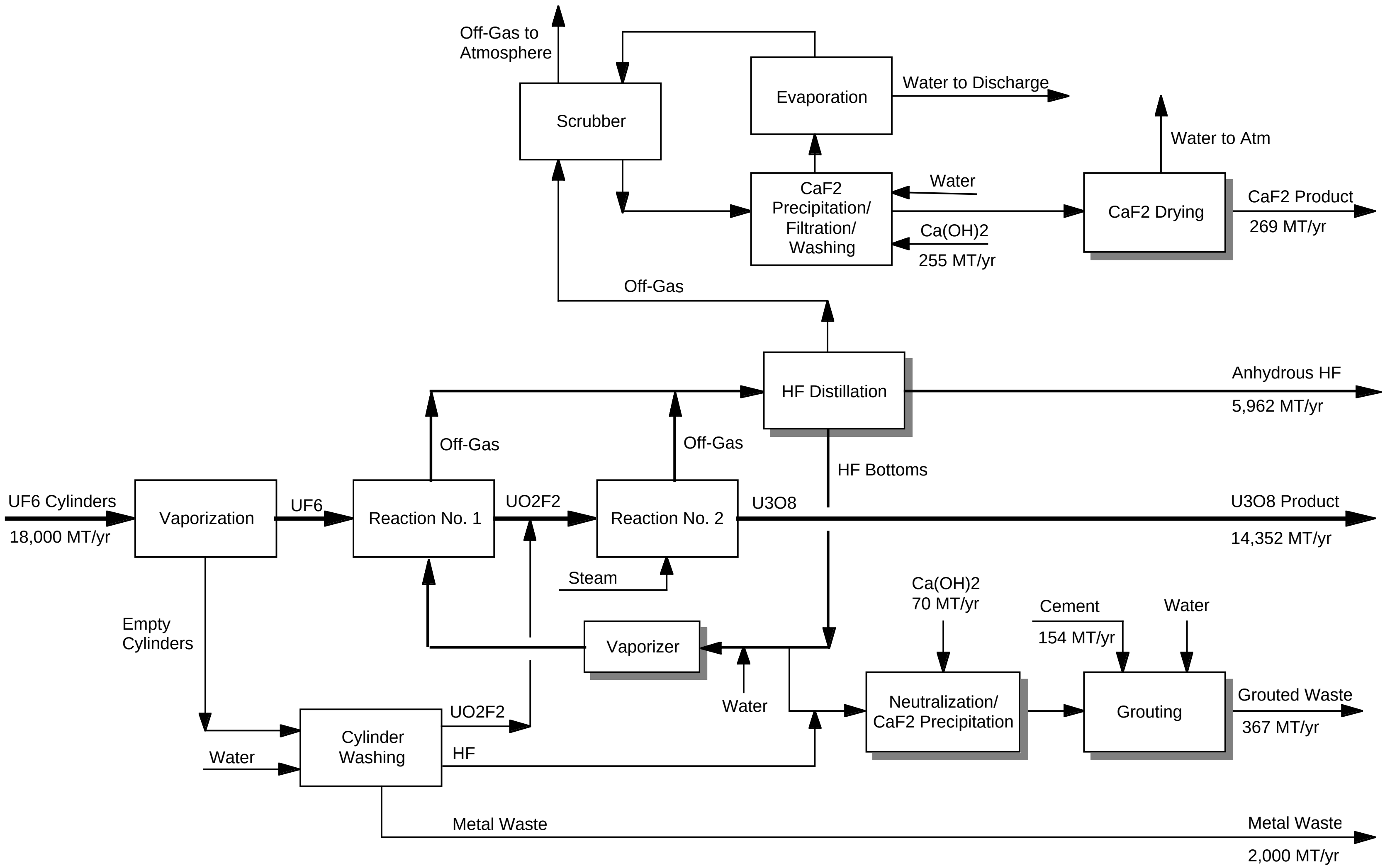
The schedule shows a construction start early in the year 2002. This appears to be attainable if the site selection, selection of contractor, and early approval for construction dates are met. The Record of Decision is expected to be issued by the end of June.

5.8 References

Initial Plan for the Conversion of Depleted Uranium Hexafluoride, as Required by Public Law 105-204, U.S. Department of Energy, 1999

Draft Engineering Analysis Report for the Long-Term Management of Depleted Uranium Hexafluoride, UCRL-AR-124080, Lawrence Livermore National Laboratory, May 1997

Uranium Hexafluoride: A Manual of Good Handling Practices, ORO-651, U.S. Department of Energy, October 1991



Note: Functions in shaded boxes are only used during the AHF production mode.

Figure 5.1 Process Block Flow Diagram—AHF Production Conversion to U3O8, AHF and CaF2

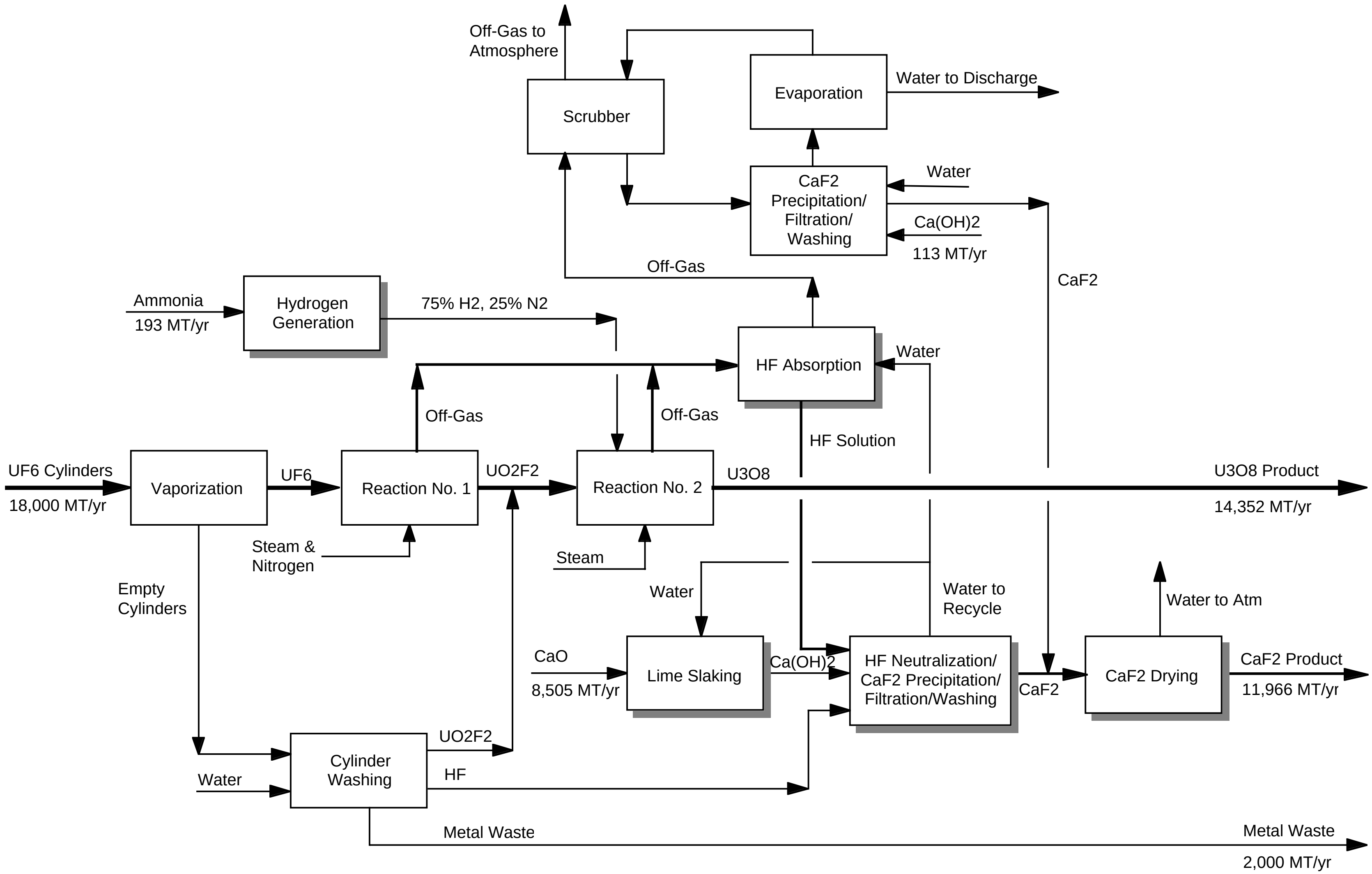


Figure 5.2 Process Block Flow Diagram – CaF2 Production
Conversion to U3O8, AHF and CaF2

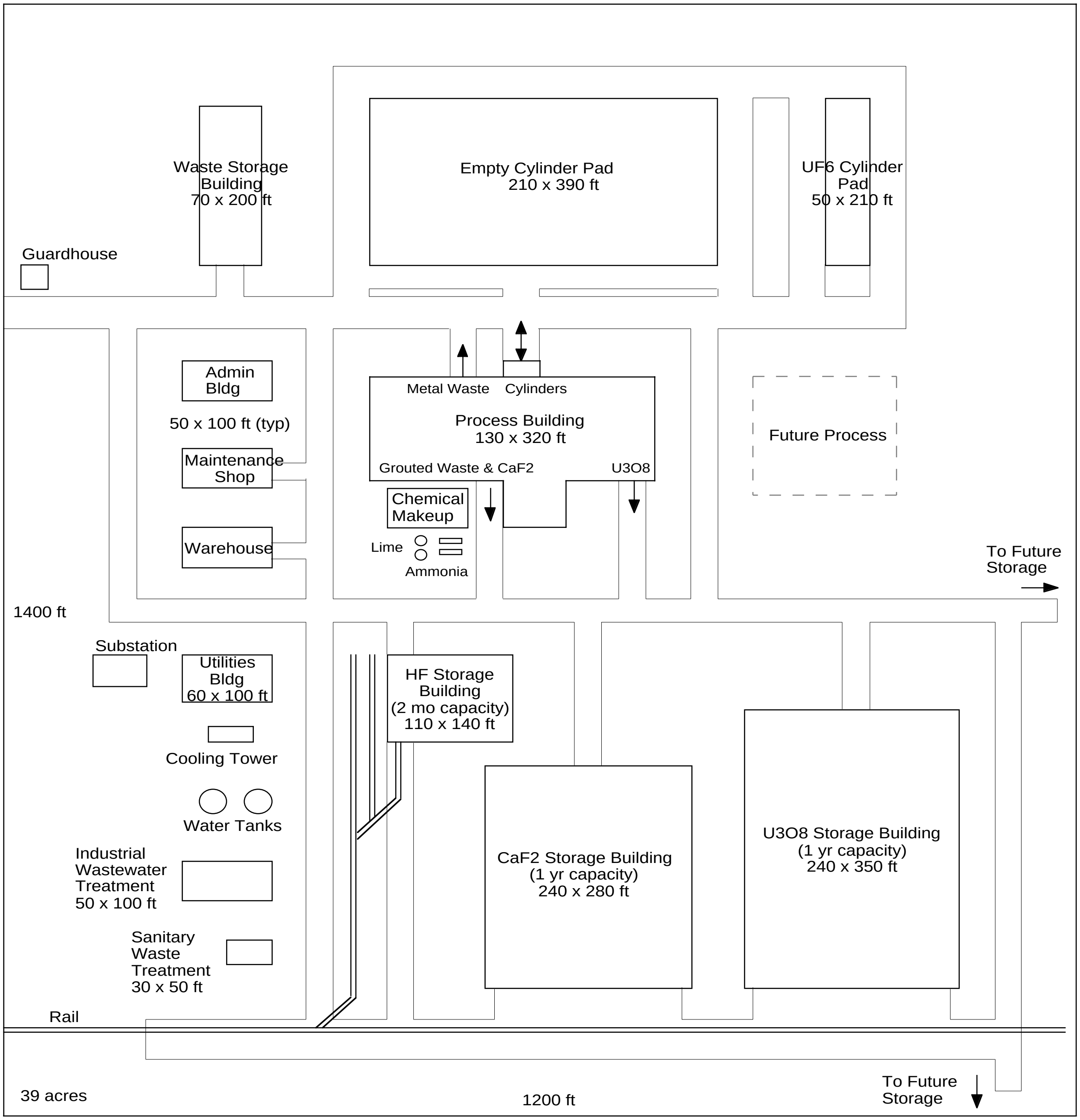


Figure 5.3 Facility Site Plan
Conversion to U3O8, AHF and CaF2

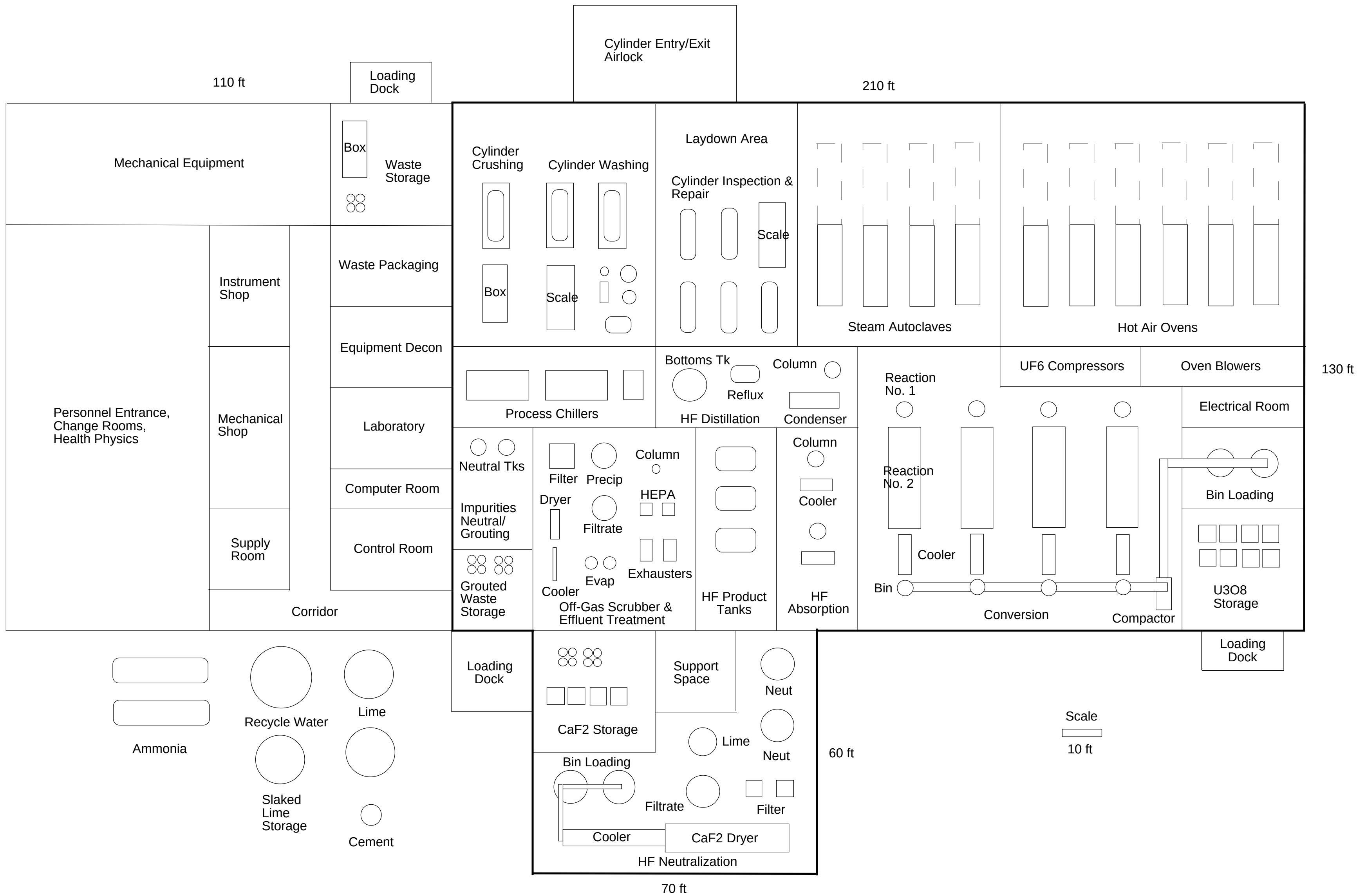


Figure 5.4 Process Building General Arrangement
Conversion to U3O8, AHF and CAF2

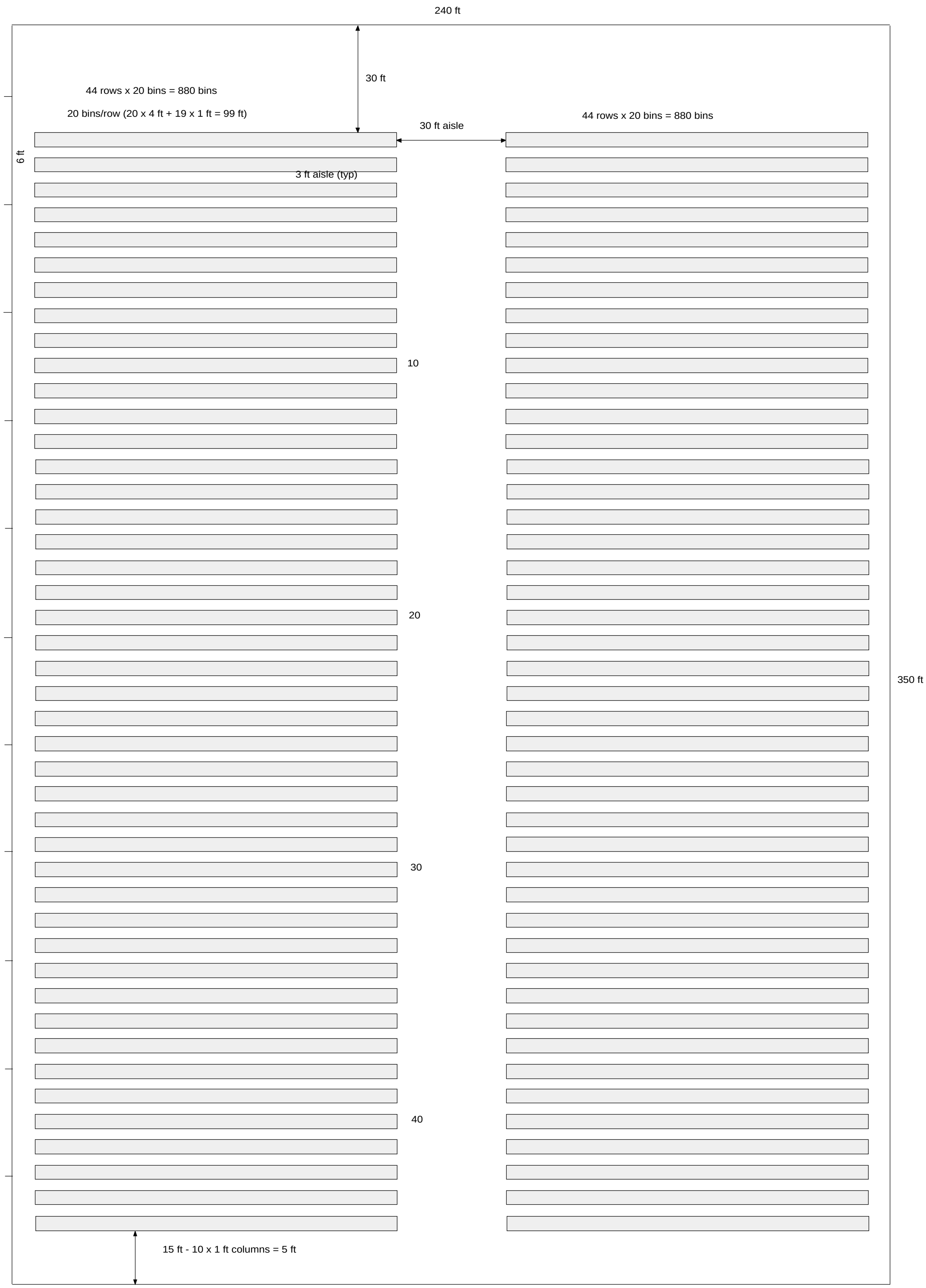
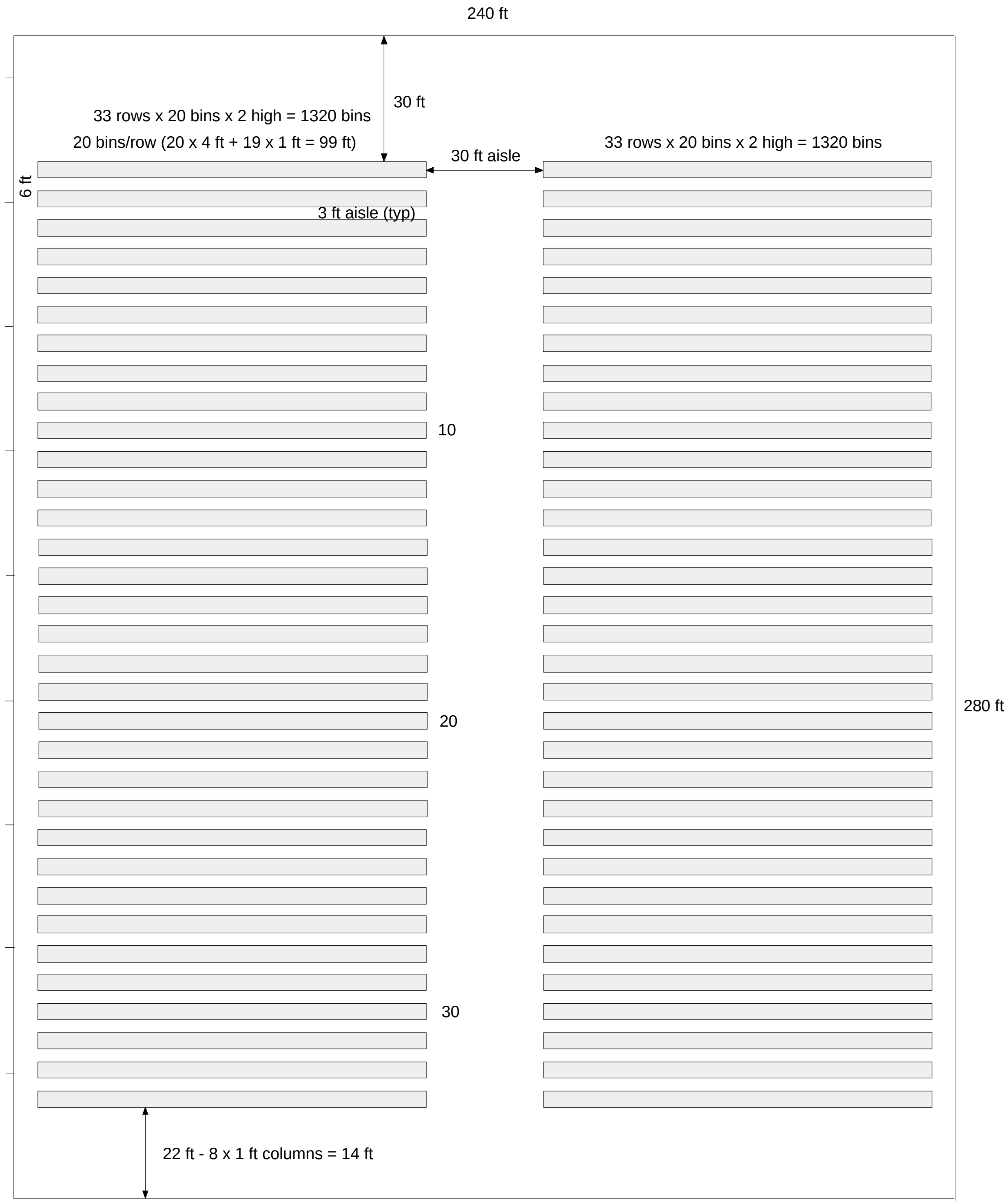


Figure 5.5 U3O8 Storage Building Plan
Conversion to U3O8, AHF and CaF2



Space provided = 2640 bins
Space required for 1 yr = 2639 bins

Figure 5.6 CaF2 Storage Building Plan
Conversion to U3O8, AHF and CaF2

Activity ID	Activity Description	Orig Dur	Early Start	Early Finish
MILESTONES				
GENERAL				
10	Record of Decision	0		30JUN99*
20	Site Selection	0		30SEP99*
30	Primary Contractor Selection	0		30APR00*
35	DOE Design Review	0		31DEC00
40	Authorize Construction	0		31MAR01
50	PSAR	0		30NOV00*
45	Select Construction Contractor	0		31OCT01
55	FSAR Approved by DOE	0		31OCT03*
60	End of Construction	0		31JAN04*
65	DOE Design/Operation Reviews	0		31JUL04*
70	Start-up & Full Operations	0		31JUL04*
PROJECT MANAGEMENT				
GENERAL				
100	Project Definition	9	01MAY99	31JAN00
105	DOE Procurement Action	9	01AUG99	30APR00
110	Site-Specific EIS	18	01NOV99	30APR01
120	Primary Contrractor Evaluation	3	01FEB00	30APR00
130	Permitting & Licensing	44	01MAY00	31DEC03
DESIGN / ENGINEERING				
GENERAL				
200	Preliminary Design	12	01MAY00	30APR01
400	Detailed Design	24	01NOV00	31OCT02
550	Construction Support	27	01NOV01	31JAN04
PROCUREMENT				
GENERAL				
600	Procurement	33	01MAY01	31JAN04
CONSTRUCTION				
PHASE 1 - PROCESS BUILDING AND SUPPORT BUILDINGS		27	01NOV01	31JAN04
PHASE 2 - STORAGE AREA		15	01MAY02	31OCT03

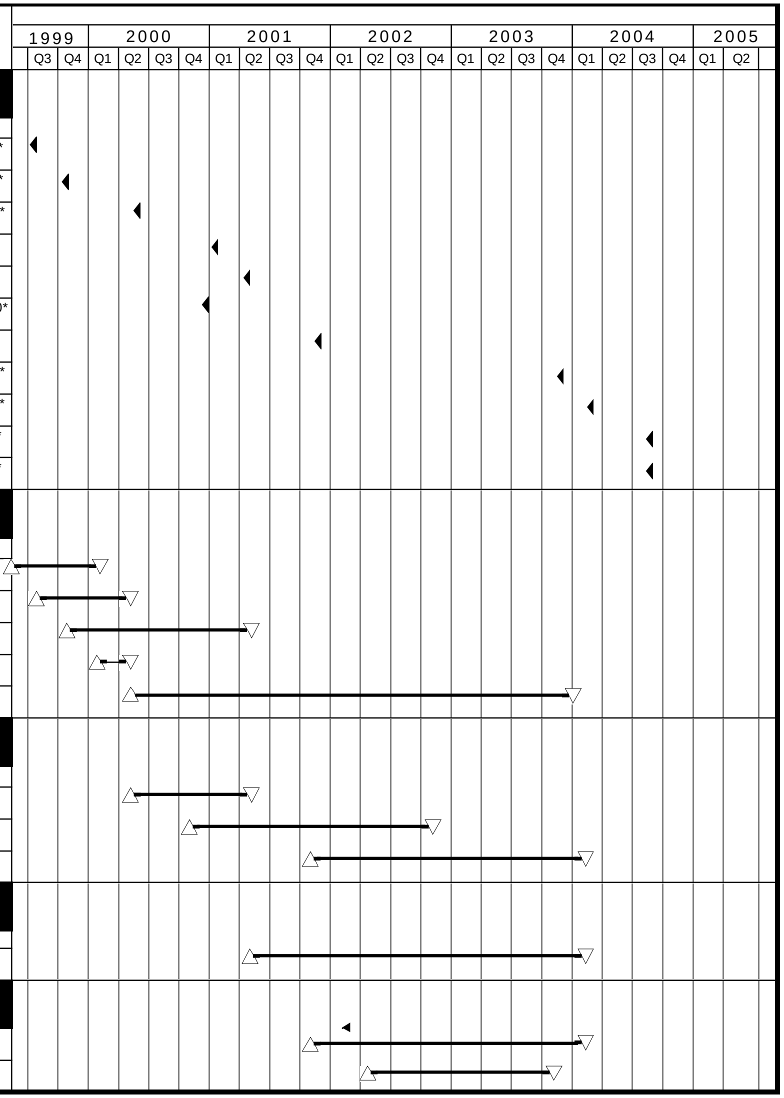


Figure 5.7 U3O8/AHF/CaF2 Plant, 25 Year Privately Owned and Operated Preliminary Project Schedule

Table 5.1
Plant Operation Manpower Estimates for
U3O8/AHF/CaF2 Conversion Facility
25 Years Privately Operated

Labor Category	Total Employees
Officials and Managers	6
Professionals	10
Technicians	16
Office and Clericals	10
Craft Workers (Maint./Production)	24
Operators	84
Line Supervision	17
Security	16
Total	**183**

Table 5.2
U3O8/AHF/CaF2 Project Capital Cost Estimate

Facility/Cost Items	Subtotal	Contingency	Total
Process Equipment	35,047,000	12,266,000	47,313,000
Process Facilities	82,581,000	28,904,000	111,485,000
Balance of Plant	32,176,000	11,261,000	43,437,000
Subtotal	149,804,000	52,431,000	202,235,000
Engineering & Design @14.4%	21,572,000	7,550,000	29,122,000
Total	**171,376,000**	**59,981,000**	**231,357,000**

Table 5.3
Operation and Maintenance Cost Estimate U3O8 / AHF / CaF2

DESCRIPTION	TOTAL ANNUAL COST U3O8 / CaF2	TOTAL ANNUAL COST U3O8 / AHF
1. Consumable and Materials		
Process Chemicals	667,617	70,957
Cooling Tower Water Treatment Chemicals	33,920	33,708
Product and Waste Containers	6,058,285	3,373,326
Scheduled Replaceable Equipment for Reaction Chambers	771,680	771,680
Facility Maintenance	655,329	655,329
Equipment Spares	946,260	946,260
Total Materials	**9,133,091**	**5,851,260**
2. Utilities & Service		
Total Utilities	**1,821,994**	**1,821,994**
3. Labor		
Plant operation labors	16,267,800	16,267,800
Off-site overhead labor	1,952,136	1,952,136
Total Labor	**18,219,936**	**18,219,936**
4. Waste Management & Disposal		
Low Level Wastes	424,500	1,169,600
Mixed Low Level Wastes	4,100	4,100
Hazardous Wastes	5,180	5,180
Total Waste Management/Disposal	**433,780**	**1,178,880**
Total Operation & Maintenance Annual Cost	**29,608,800**	**27,072,070**
Start-Up Cost Facility start-up cost based on allowance of 65% of one year O&M total labor cost.	**11,842,958**	**11,842,958**
Total O&M Cost for 25 years	**752,062,967**	**688,644,698**

Table 5.5 Expenditure Funding Profile
U3O8/AHF/CaF2 25 Years POPO
10-year payback
AHF Production Mode (in million FY2000 dollars)

	TOTAL	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09
Construction Investment:												
NEPA/Licensing	5.0		0.5	1.3	1.3	1.3	0.5					
Engineering	29.1		3.6	13.4	9.0	2.7	0.4					
Construction	202.2	0.2	2.0	5.4	37.2	120.7	36.7					
Start-up	11.8						11.8					
Total Investment Loan	248.2	0.2	6.0	20.2	47.6	124.7	49.4					
Accumulated Debt:		0.2	6.8	29.3	83.4	225.8	298.7	278.5	256.7	233.0	207.3	179.4
Operation Expenses:												
Debt Payment	455.2							45.5	45.5	45.5	45.5	45.5
Operation & Maintenance	676.8						4.5	27.1	27.1	27.1	27.1	27.1
Decon &Decommission	23.1											
Total Operation Expenses	1155.1						4.5	72.6	72.6	72.6	72.6	72.6
Revenues:												
Break-even Conversion Revenue	926.5						10.7	64.1	64.1	64.1	64.1	64.1
HF Product Sales	228.6						1.5	9.1	9.1	9.1	9.1	9.1
Total Revenue	1155.1						12.2	73.2	73.2	73.2	73.2	73.2
Cash Funding Requirements:	719.5	0.2	6.0	20.2	47.6	124.7	52.4	17.9	17.9	17.9	17.9	17.9
Break-even Government Payment:	926.5						10.7	64.1	64.1	64.1	64.1	64.1

Notes: Cash funding requirements reflect cash flow required for construction and operating minus revenue from AHF sales. Break-even government payment is the funding from DOE paid to the private plant owner for the conversion service to cover the break-even cost for construction loan payment, operation, and D&D only; no profits included.

Assumptions:

Loan Interest Rate @ 8.5% for Construction Loan during construction period
Loan Interest Rate @ 8.5% for payback in 10 years at start of operation

Chemical Sale Price: 70 ¢/lb of HF

Table 5.5, continued Expenditure Funding Profile
U3O8/AHF/CaF2 25 Years POPO
10-year payback
AHF Production Mode
(in million FY2000 dollars)

	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
Construction Investment:													
NEPA/Licensing													
Engineering													
Construction													
Start-up													
Total Investment Loan													
Accumulated Debt:	149.1	116.3	80.6	42.0	0.0								
Operation Expenses:													
Debt Payment	45.5	45.5	45.5	45.5	45.5								
Operation & Maintenance	27.1	27.1	27.1	27.1	27.1	27.1	27.1	27.1	27.1	27.1	27.1	27.1	27.1
Decon &Decommission													
Total Operation Expenses	72.6	72.6	72.6	72.6	72.6	27.1	27.1	27.1	27.1	27.1	27.1	27.1	27.1
Revenues:													
Break-even Conversion Revenue	64.1	64.1	64.1	64.1	64.1	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6
HF Product Sales	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Total Revenue	73.2	73.2	73.2	73.2	73.2	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7
Cash Funding Requirements:	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9
Break-even Government Payment:	64.1	64.1	64.1	64.1	64.1	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6

Table 5.5, continued Expenditure Funding Profile
U3O8/AHF/CaF2 25 Years POPO
10-year payback
AHF Production Mode
(in million FY2000 dollars)

	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32
Construction Investment:										
NEPA/Licensing										
Engineering										
Construction										
Start-up										
Total Investment Loan										
Accumulated Debt:										
Operation Expenses:										
Debt Payment										
Operation & Maintenance	27.1	27.1	27.1	27.1	27.1	27.1	22.6			
Decon &Decommission								11.6	11.6	
Total Operation Expenses	27.1	27.1	27.1	27.1	27.1	27.1	22.6	11.6	11.6	
Revenues:										
Break-even Conversion Revenue	18.6	18.6	18.6	18.6	18.6	18.6	15.5			
HF Product Sales	9.1	9.1	9.1	9.1	9.1	9.1	7.6			
Total Revenue	27.7	27.7	27.7	27.7	27.7	27.7	23.1			
Cash Funding Requirements:	17.9	17.9	17.9	17.9	17.9	17.9	14.9	11.6	11.6	
Break-even Government Payment:	18.6	18.6	18.6	18.6	18.6	18.6	15.5			

Table 5.6 Expenditure Funding Profile
U3O8/AHF/CaF2 25 Years POPO
10-year payback
CaF2 Production Mode (in million FY2000 dollars)

	TOTAL	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09
Construction Investment:												
NEPA/Licensing	5.0		0.5	1.3	1.3	1.3	0.5					
Engineering	29.1		3.6	13.4	9.0	2.7	0.4					
Construction	202.2	0.2	2.0	5.4	37.2	120.7	36.7					
Start-up	11.8						11.8					
Total Investment Loan	248.2	0.2	6.0	20.2	47.6	124.7	49.4					
Accumulated Debt:		0.2	6.8	29.3	83.4	225.8	298.7	278.5	256.7	233.0	207.3	179.4
Operation Expenses:												
Debt Payment	455.2							45.5	45.5	45.5	45.5	45.5
Operation & Maintenance	740.2						4.9	29.6	29.6	29.6	29.6	29.6
Decon &Decommission	23.1											
Total Operation Expenses	1218.6						4.9	75.1	75.1	75.1	75.1	75.1
Revenues:												
Break-even Conversion Revenue	1218.6						12.6	75.8	75.8	75.8	75.8	75.8
HF Product Sales	N/A											
Total Revenue	1218.6						12.6	75.8	75.8	75.8	75.8	75.8
Cash Funding Requirements:	1011.6	0.2	6.0	20.2	47.6	124.7	54.4	29.6	29.6	29.6	29.6	29.6
Break-even Government Payment:	1218.6						12.6	75.8	75.8	75.8	75.8	75.8

Notes: Cash funding requirements reflect cash flow required for construction and operating minus revenue from AHF sales. Break-even government payment is the funding from DOE paid to the private plant owner for the conversion service to cover the break-even cost for construction loan payment, operation, and D&D only; no profits included.

Assumptions:

Loan Interest Rate @ 8.5% for Construction Loan during construction period

Loan Interest Rate @ 8.5% for payback in 10 years at start of operation

Table 5.6, continued Expenditure Funding Profile
U3O8/AHF/CaF2 25 Years POPO
10-year payback
CaF2 Production Mode
(in million FY2000 dollars)

	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
Construction Investment:													
NEPA/Licensing													
Engineering													
Construction													
Start-up													
Total Investment Loan													
Accumulated Debt:	149.1	116.3	80.6	42.0	0.0								
Operation Expenses:													
Debt Payment	45.5	45.5	45.5	45.5	45.5								
Operation & Maintenance	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6
Decon &Decommission													
Total Operation Expenses	75.1	75.1	75.1	75.1	75.1	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6
Revenues:													
Break-even Conversion Revenue	75.8	75.8	75.8	75.8	75.8	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2
HF Product Sales													
Total Revenue	75.8	75.8	75.8	75.8	75.8	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2
Cash Funding Requirements:	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6
Break-even Government Payment:	75.8	75.8	75.8	75.8	75.8	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2

Table 5.6, continued Expenditure Funding Profile
U3O8/AHF/CaF2 25 Years POPO
10-year payback
CaF2 Production Mode
(in million FY2000 dollars)

	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32
Construction Investment:										
NEPA/Licensing										
Engineering										
Construction										
Start-up										
Total Investment Loan										
Accumulated Debt:										
Operation Expenses:										
Debt Payment										
Operation & Maintenance	29.6	29.6	29.6	29.6	29.6	29.6	24.7			
Decon &Decommission								11.6	11.6	
Total Operation Expenses	29.6	29.6	29.6	29.6	29.6	29.6	24.7	11.6	11.6	
Revenues:										
Break-even Conversion Revenue	30.2	30.2	30.2	30.2	30.2	30.2	25.2			
HF Product Sales										
Total Revenue	30.2	30.2	30.2	30.2	30.2	30.2	25.2			
Cash Funding Requirements:	29.6	29.6	29.6	29.6	29.6	29.6	24.7	11.6	11.6	
Break-even Government Payment:	30.2	30.2	30.2	30.2	30.2	30.2	25.2			

6. DUF6 Conversion to UO2/AHF

6.1 Introduction

About 700,000 metric tons (MT) of depleted uranium hexafluoride (DUF6) are currently stored at the Paducah, Portsmouth and Oak Ridge sites. Public Law 105-204 requires the DOE to submit to Congress a plan to ensure that all funds accrued on the books of USEC for disposition of DUF6 will be used for the construction and operation of plants to treat and recycle the DUF6. The Department of Energy's Initial Plan calls for construction to begin in the year 2002 time frame.

This report section examines the cost and issues for plant construction based on a conversion plant using a dry process to convert DUF6 to uranium dioxide aggregate and anhydrous hydrogen fluoride (AHF) as final products. The UO2 aggregate can be used to make dense concrete for shielding applications. The construction and operation of the conversion plant is based on private ownership with DOE regulations and operating for 25 years.

A preconceptual plant design, rough cost estimate, and preliminary project schedule were developed. The integrated conversion plant includes capabilities for DUF6 cylinder preparation, conversion of DUF6 to uranium dioxide (UO2) and fluorine byproducts, manufacture of UO2 aggregate, empty cylinder treatment for disposal, and interim storage for UO2 aggregate and byproducts.

Significant design bases for the conversion plant include:

- The plant will convert DUF6 to UO2 by a dry process. Hydrogen fluoride (HF) off-gas will be treated to produce AHF and a minor quantity of calcium fluoride (CaF2).
- The UO2 will be mixed with additives, pressed into pellets, and sintered to produce dense UO2 aggregate. The aggregate is assumed to be 93% UO2, sintered at 1300°C, have a final diameter and length of 3/4 inch, and a particle density of 8 g/cc.
- The plant capacity will be based on a 25 year operating period to process a DUF6 inventory of 36,910 cylinders (450,000 MT DUF6) over the life of the plant.
- Storage will be provided for one year production of UO2 aggregate and CaF2 product and two months production of AHF.
- The AHF product is available for sale by plant owner to commercial users. The UO2 aggregate and CaF2 products are returned to the DOE.
- To bound costs associated with empty cylinders, assume all empty cylinders will be washed, compacted, and returned to the DOE for disposal.
- The plant will be on a DOE owned site at or near a gaseous diffusion plant and include the support facilities and infrastructures/utilities needed for a greenfield facility.
- The design will consider addition of future process and storage buildings.

6.2 Summary of Results

The plant annually processes 18,000 MT of UF6 contained in 1,476 cylinders to produce 14,846 MT of 93% UO2 aggregate, 5,944 MT of AHF, 304 MT of CaF2, and 2,000 MT of empty cylinder metal waste. The plant, which includes a one year storage capacity for UO2 aggregate and CaF2 and two months storage capacity for AHF, occupies about 37 acres. Additional storage capacity would require about 4 acres for each year of additional UO2 aggregate storage.

The construction capital cost estimate is $206 million for the plant facilities. The engineering cost is about $30 million. Each year of additional UO2 storage would be $13 million. These costs are in 1st Quarter FY2000 dollars.

The annual operation and maintenance (O&M) cost is about $28 million. The O&M cost does not include disposal of empty cylinder metal. Cost for NEPA, regulatory and licensing activities is estimated at $5 million. Decontamination and decommissioning (D&D) cost is estimated at $24 million.

The preliminary schedule assumes selection of a private plant contractor in April 2000. The schedule shows plant engineering design starting in May 2000, construction beginning in November 2001, plant completion in January 2004, and full operation beginning in July 2004. Peak engineering personnel is 80 persons and peak employment during construction is about 450 persons. Plant employment during operations is 191 persons.

The 2002 construction start depends on the key milestone dates for site selection, selection of primary contractor and construction contractor, and construction approval. The schedule includes NEPA activities, as a site-specific EIS is required, and DOE regulatory activities. The amount of UO2 aggregate storage provided affects cost and may need additional study. Process design criteria for UF6 cylinder vaporization, conversion reaction chamber, HF distillation, and empty cylinder treatment are necessary to ensure successful facility design and operation.

6.3 Conversion Process Description

Depleted uranium hexafluoride (DUF6) is processed to produce UO2 aggregate and AHF. The average throughput is 5 cylinders per day (5,670 lb/hr DUF6) based on 80% plant availability (7,000 hours/yr or 292 days/yr). The process block flow diagram is shown in Figure 6.1.

The DUF6 is shipped by truck from the cylinder yards at the gaseous diffusion plant to an outdoor storage pad at the Conversion Facility. The cylinder is moved into the Process Building for inspection and preparation. The cylinders are loaded into steam-heated autoclaves to vaporize the DUF6 for feeding into the conversion process. Cylinders with questionable integrity are loaded into hot air ovens where the solid UF6 sublimes into a gas under vacuum. This avoids melting the DUF6 and pressurizing the cylinder, which occurs when using an autoclave. Several of the cylinders may be substandard based on the DUF6 Engineering Analysis Report (p. 6.1-4-5).

The UF6 gas is converted to UO2 in a series of two reaction chambers, where it is mixed with an HF/water vapor mixture in the first reaction chamber and with steam, nitrogen and hydrogen in the second reaction chamber. The chemical reactions are:

$UF6 + 2\ H_2O \text{ ---> } UO2F_2 + 4\ HF$

$UO2F_2 + H_2 \text{ ---> } UO2 + 2\ HF$

Four reaction lines are provided to meet the required throughput. The UO2 product is cooled and conveyed to indoor silos for interim storage.

Reaction chamber off-gas containing HF, steam, nitrogen and hydrogen is filtered to remove uranium particulates. The off-gas then flows to an HF distillation system, which concentrates the mixture to produce anhydrous HF in the overhead product. The AHF is collected, sampled, and pumped to large storage tanks in the HF Storage Building, where the AHF is loaded into railcars or tank trucks for delivery to customers. The AHF is expected to contain less than 1 ppm uranium.

The aqueous hydrogen fluoride bottoms stream from HF distillation is collected, vaporized and recycled to the first reaction chamber. To prevent the buildup of impurities in the recycle stream, a small fraction is withdrawn. This purge stream is neutralized with hydrated lime, mixed with cement and water to form a grout, and packaged in drums for disposal.

Off-gas from the distillation column, primarily nitrogen, hydrogen and air inleakage, flows to the scrubber system. Residual HF in the off-gas is removed by scrubbing with a potassium hydroxide (KOH) solution. The off-gas is then HEPA-filtered and discharged to the atmosphere. The spent scrub solution is regenerated with hydrated lime ($Ca(OH)_2$), which produces a calcium fluoride (CaF2) byproduct. The chemical reactions are:

$HF + KOH \text{--->} KF + H_2O$

$2\ KF + Ca(OH)_2 \text{--->} CaF2 + 2\ KOH$

The CaF2 is separated by filtering, washed with water, dried and loaded into drums. The drums, containing 700 lb of CaF2, are transferred to the CaF2 Storage Building. The CaF2 is expected to contain less than 1 ppm uranium.

The UO2 powder is converted to pellets suitable for use as aggregate in dense concrete shielding applications. The composition, sintering temperature and dimensions of the aggregate product are being developed and the design parameters mentioned below are nominal values only.

The first step in pelletization is to mix the UO2 powder with additives to produce a 93% UO2 mixture. The mixture is milled, screened to remove oversize material, and agglomerated into granules to enable reproducible and dust-free feeding to a powder compacting press. The press produces cylindrical pellets that are nominally 1 inch diameter by 1 inch high. The pellets are loaded onto trays, which are moved by conveyor into a sintering furnace. The pellets are sintered at 1300°C in a hydrogen atmosphere to form dense, ceramic pellets. The sintered pellets (UO2 aggregate), which are about 3/4 inch diameter by 3/4 inch high, are unloaded from the trays and loaded into metal boxes. The 60 cu ft box is about 4x4x4 ft tall and hold 8.5 tons (7.7 MT) of UO2 aggregate. The filled boxes are transferred to the UO2 Storage Building.

After vaporization, the empty cylinders are transferred to an outdoor pad and stored for three months. This allows for radioactive decay of non-volatile daughter products in the cylinder. The cylinders are then brought into the Process Building, washed with water, crushed, and loaded into boxes. Each 6x14x3 ft high box contains about 9,000 lb of metal from three crushed cylinders. The filled boxes are stored in the Waste Storage Building and transported to the gaseous diffusion plant for disposition. The cylinder wash effluents are fed into the main conversion processes.

Major process materials and annual quantities are summarized below:

Major Input Streams	Major Output Streams
Depleted Uranium Hexafluoride 18,000 MT/yr 1476 cylinders/yr	Uranium Dioxide Aggregate (93% UO2) 14,846 MT/yr 1926 4x4x4 ft boxes/yr (17,000 lb/box) or 29,760 30-gal drums/yr (1100 lb/drum)
Hydrated Lime $Ca(OH)_2$ 358 MT/yr 9600 ft3/yr	Anhydrous Hydrogen Fluoride (HF) 5944 MT/yr 1.64 million gal/yr
Cement 154 MT/yr 2890 ft3/yr	Calcium Fluoride (CaF2) 304 MT/yr 958 55-gal drums/yr (700 lb/drum)
Aggregate Additives 1039 MT/yr 30,600 ft3/yr	Empty Cylinder Metal Waste 2000 MT/yr 492 6x14x3 (H) ft boxes/yr (9000 lb/box)
Ammonia (NH_3) 838 MT/yr 364,000 gal/yr	Grouted Waste 367 MT/yr 1012 55-gal drums/yr (800 lb/drum)

Major process equipment includes four steam autoclaves, six hot air ovens, four reaction chamber lines, UO2 blending system, two lines of powder preparation and compacting equipment, five sintering furnaces, a box loading system, an HF distillation system, off-gas scrubbing system, neutralization/grouting system, two empty cylinder washing machines and one cylinder crusher.

6.4 Conversion Plant Description

The Conversion Facility is assumed to be constructed on a DOE site at a greenfield location at or near a gaseous diffusion plant. The Conversion Facility occupies about 37 acres. Additional storage buildings for UO2 aggregate could be built adjacent or at a nearby location. Each additional one year increment of UO2 aggregate storage occupies 4 acres. A conceptual site plan for the Conversion Facility is shown in Figure 6.2.

The Conversion Facility includes full and empty cylinder storage pads, the Process Building, a UO2 aggregate Storage Building, an HF Storage Building , a CaF2 Storage Building, a Waste Storage Building and support facilities. The site plan considers addition of future process facilities such as uranium metal.

The Conversion Facility will be designed and constructed in compliance with DOE Orders and applicable regulations and codes, and will meet the intent of NRC standards. In general, a graded approach as established in DOE Order 420.1 is used for the design of all structures, systems, and components (SSC) in the plant facilities. All SSC’s will be assigned a Natural Phenomena Performance Category using the criteria in the DOE Standards DOE-STD-1020-94 and DOE-STD-1021-93 during the design phase.

In the absence of a hazard analysis, it is assumed that the Process Building is performance category PC-3 to control and confine hazardous material. The building structure is reinforced concrete construction in the processing areas. The remainder of the building housing the personnel support area is steel frame, metal siding construction. The Process Building is 30 ft high in the processing areas and 18 ft high in the support areas. HVAC equipment is located on a mezzanine level. The process room air is filtered through one stage of HEPA filters prior to discharge to atmosphere. The Process Building general arrangement is shown in Figure 6.3.

The UO2 Storage Building and CaF2 Storage Building have a one year capacity. The UO2 Building holds 2000 boxes stacked two high, and the CaF2 Building holds 958 drums stacked two high. The Waste Building has a one month capacity for staging treated empty cylinders and process waste for transport offsite. The UO2, CaF2, and waste storage buildings are assumed PC-2 to maintain storage function after the occurrence of a natural phenomena hazards event. These buildings are steel frame and concrete clad panel construction and are ventilated and lighted, but no heating, cooling or HEPA filtration is provided. Access aisles allow personnel to inspect the bins during storage. A general storage arrangement in the UO2 Building is shown in Figure 6.4.

The HF Storage Building has a two months capacity with ten 34,000-gallon storage tanks. The HF Storage Building is assumed PC-3 to control and confine hazardous material. The building structure is reinforced concrete construction. The HF storage tanks are housed separately in cell rooms.

Plant operations are assumed to be continuous for 24 hours/day, 7 days/week, 52 weeks/year. Due to seven day per week operation, a fourth shift is necessary to account for normal days off for employees. The number of employees during operation is estimated to be 191 persons, with 68 employees on day shift and 41 each of the other three shifts. The numbers are estimated based on process operation labor and facility support labor requirements needed to operate the plant. A breakdown of the plant operation employees by category and by shift is shown in Table 6.1.

6.5 Cost Estimate

The cost estimates are rough order of magnitude estimates based on a preconceptual level design information. The cost estimate results are summarized below:

	Cost ($million)	**Contingency ($million)**	**Total Cost ($million)**
Conversion Facility			
Engineering	--	--	30
Plant Facilities Construction Cost	153	53	206
Startup Cost	--	--	12
Annual Operations and Maintenance Cost (O&M)	--	--	28
Decontamination and Decommissioning (D&D)	--	--	24
Additional Storage			
Engineering	--	--	1.1
UO2 Storage (1 yr capacity) Construction Cost	11	2	13
NEPA/Licensing	--	--	5

The estimates do not include costs for plant design criteria development, cost of land, site qualifications, or extension of local roads and utility lines to the site boundary. The estimates take into account the labor productivity and indirect cost factors for a privately run project. Cost estimate bases are described in the Appendix.

The construction capital costs are based on an engineering, procurement and construction management (EPCM) approach. Capital costs, see Table 6.2, are reported in 1st quarter fiscal year 2000 dollars (October 1999). Labor costs are based on local wage rates at a generic gaseous diffusion plant located in mid-U.S.A. The capital cost estimate utilized historical cost data, estimating manuals, allowances and budgetary quotations. A 35% contingency was applied to the capital costs for the Conversion Facility and 15% for the subsequent Storage Facilities. These contingency levels are based on previous risk analysis on projects of similar scope and level of design details. Engineering cost was estimated at 14.4% of the capital costs for the Conversion Facility and 8% for the subsequent Storage Facilities. The lower percentages are used for the subsequent Storage Facilities because previous building engineering design can be reused. Product and waste container costs are included in the O&M costs. The D&D cost was estimated as 10% of the capital cost.

The O&M cost includes costs for materials, utilities, labor, and waste disposal, see Table 6.3. Plant startup cost was assumed to be 65% of the annual O&M labor cost. The annual O&M cost does not include the cost for disposal of empty cylinder metal waste. If the empty cylinder metal is to be disposed as low-level waste (LLW), the estimated disposal cost would range from $1 million to $12 million annually, depending on the disposal sites. Revenue from sales of AHF is also not included in the O&M cost. The O&M cost includes $1.8 million a year for boxes to package the UO2 product. This cost could be saved if the empty boxes are returned from customers and reused.

The annual expenditure required to support the construction and operation of the conversion plant for the initial project years is shown in Table 6.4. The expenditure profile for all years is shown below. The expenditure profiles are derived from loading the estimated capital and operating costs onto the project schedule. A constant FY2000 dollar value is used in the expenditure outlay because of the difficulty in accurately projecting the inflation rate for future years.

6.6 Project Schedule

An estimated preliminary project schedule is shown in Figure 6.5. The schedule allows 2.5 years for engineering design and 2 years for construction. The schedule is based on a fast track premise with overlapping engineering phases and early procurement of some key equipment (most equipment is available in 12-18 month lead time) and a two-phase construction plan. The estimated peak engineering personnel is 80 persons and peak employment during construction is 450 persons.

6.7 Discussion and Issues

6.7.1 Process

Boxes were used to package the UO2 aggregate because of the space savings compared to drums. Using boxes instead of drums significantly reduces the storage building area. If only a limited amount of UO2 aggregate is to be stored, drums may be preferable due to easier handling. Additional study is needed to determine the best storage container to use with the cost considerations on facilities and transport.

In cylinder washing, the empty cylinders are cleaned to remove the reactive fluoride materials inside the cylinder. It was assumed that the metal from washed empty cylinders is returned to the DOE for disposal. The residual uranium contaminated cylinders might require the cylinder metal to be disposed of as LLW.

Alternate dispositions include recycling and reusing the radioactively-contaminated carbon steel for LLW containers for further use in the nuclear industry or decontaminating the metal sufficiently for disposal as non-hazardous waste or scrap.

6.7.2 Facility

Buildings for processing and storage were assumed to be performance category PC-2 or PC-3. A safety and accident analysis was not performed and is needed to determine the hazard classification and performance category. The appropriate structure for buildings housing large quantities of UO2 needs study.

The DUF6 Engineering Analysis Report has identified issues with federal (49CFR173.420) or ANSI N14.1 transportation requirements and overpressured, overfilled or substandard cylinders. The Report suggests that a new overpack be designed and licensed if filled substandard cylinders must be shipped from off-site. The cost of overpacks is not considered in the report. This transportation issue still needs to be resolved.

The preconceptual plant design is essentially a single line plant. Multiple autoclaves, ovens, conversion reaction chambers, and sintering furnaces are provided to obtain the design throughput. The HF distillation system, off-gas scrubber, and impurity neutralization units are single line systems with installed spares on maintenance-prone items such as pumps and filters. A RAM (reliability, availability, maintainability) analysis may help determine if this configuration is satisfactory and whether independent parallel lines might be desirable.

6.7.3 Cost Estimate

The cost estimate is based on a privately owned and privately operated plant located on a government facility site. The major contributors to the capital cost are the Process Building including the structure and service systems. The major process equipment costs are the cylinder handling crane, autoclaves, hot air ovens and DUF6 compressors, conversion reaction chambers, sintering furnaces, distillation equipment, and cylinder tilt and roll wash stands. The cost of boxes to package the UO2 aggregate is about $1.8 million a year. Significant cost could be saved if the boxes are recycled from UO2 aggregate users. The cost to dispose of empty cylinder metal is not included in this report. If it is disposed as LLW, the disposal cost could be significant.

6.7.4 Schedule

The schedule shows a construction start early in the year 2002. This appears to be attainable if the site selection, selection of contractor, and early approval for construction dates are met. The Record of Decision is expected to be issued by the end of June.

6.8 References

Initial Plan for the Conversion of Depleted Uranium Hexafluoride, as Required by Public Law 105-204, U.S. Department of Energy, 1999

Draft Engineering Analysis Report for the Long-Term Management of Depleted Uranium Hexafluoride, UCRL-AR-124080, Lawrence Livermore National Laboratory, May 1997

Uranium Hexafluoride: A Manual of Good Handling Practices, ORO-651, U.S. Department of Energy, October 1991

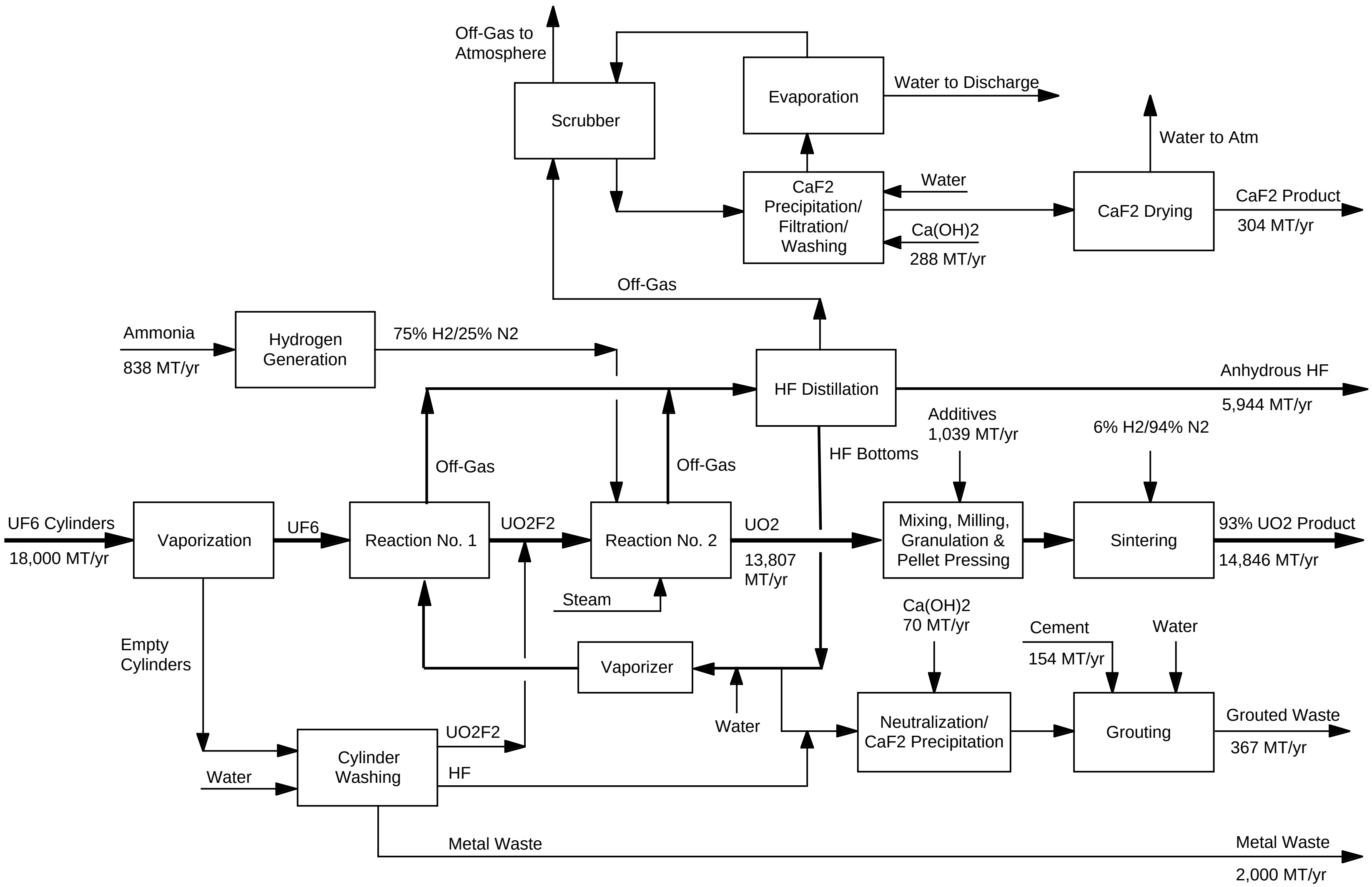


Figure 6.1 Process Block Flow Diagram
Conversion to UO2 and AHF

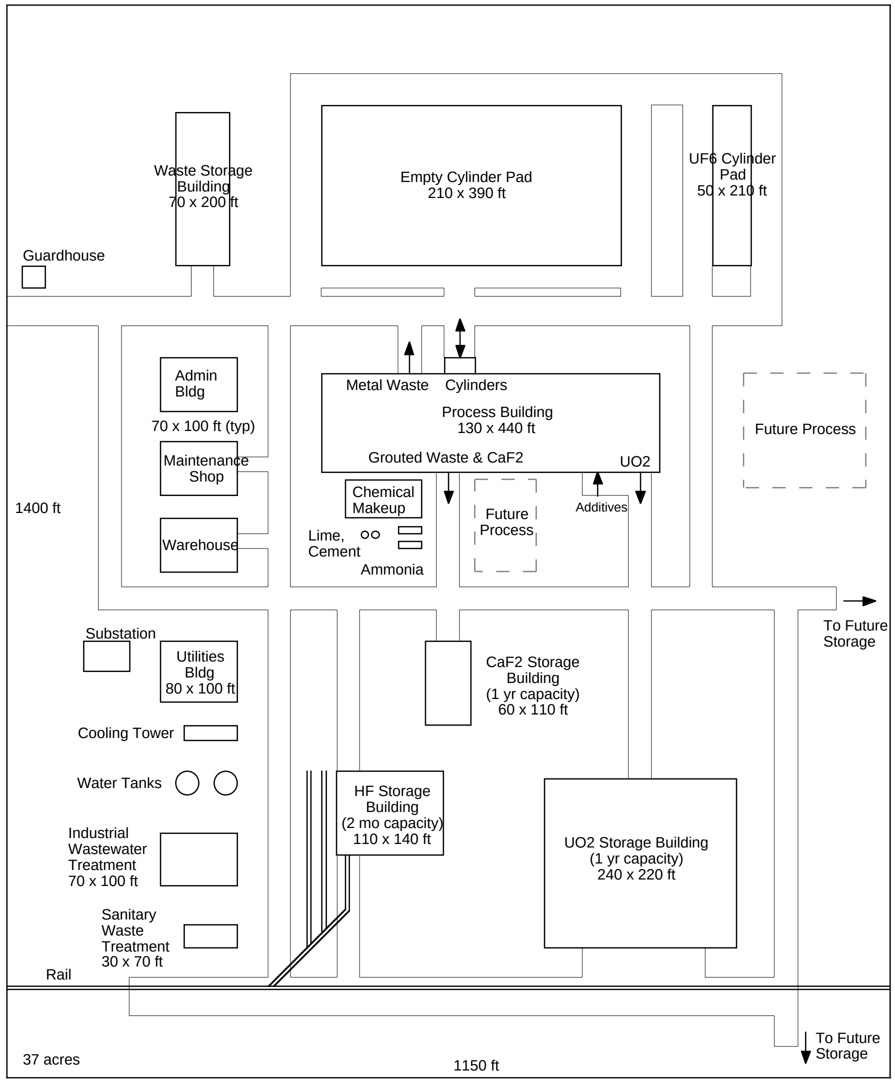


Figure 6.2 Facility Site Plan
Conversion to UO2 and AHF

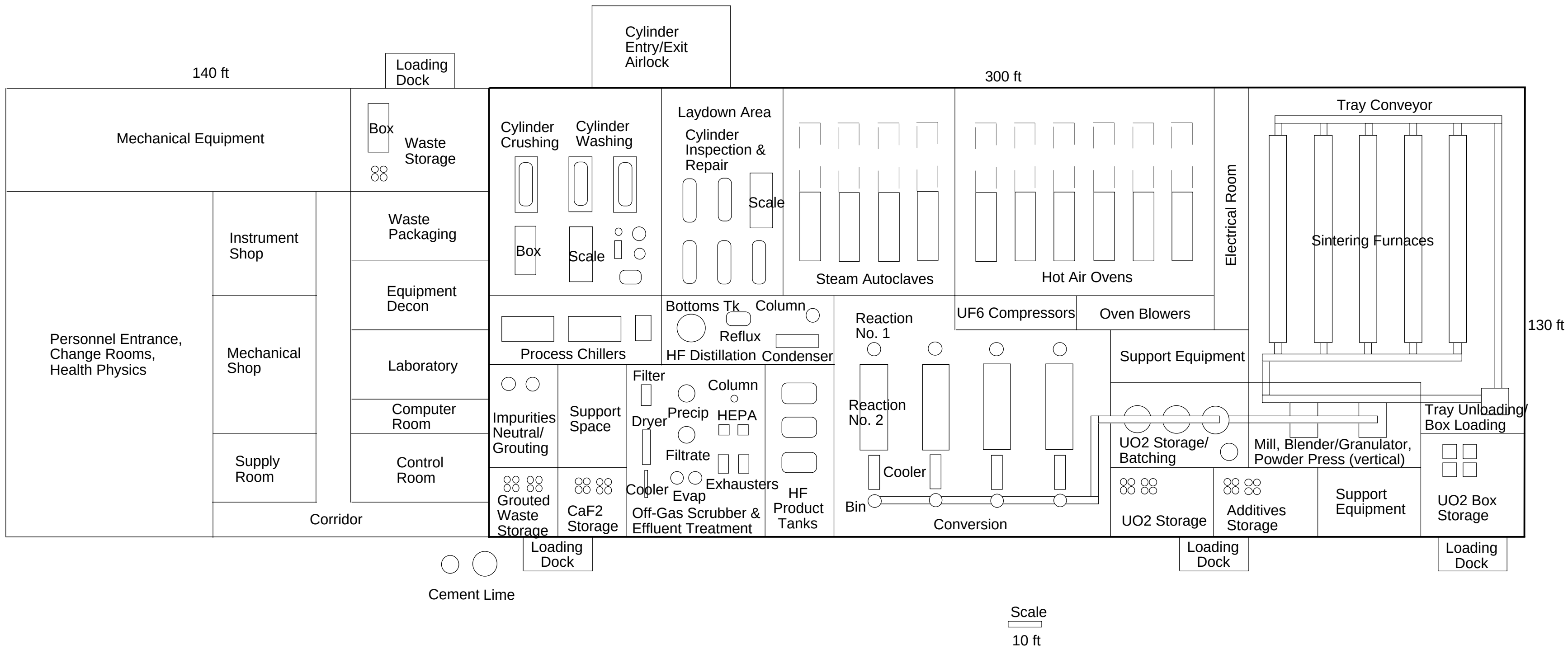
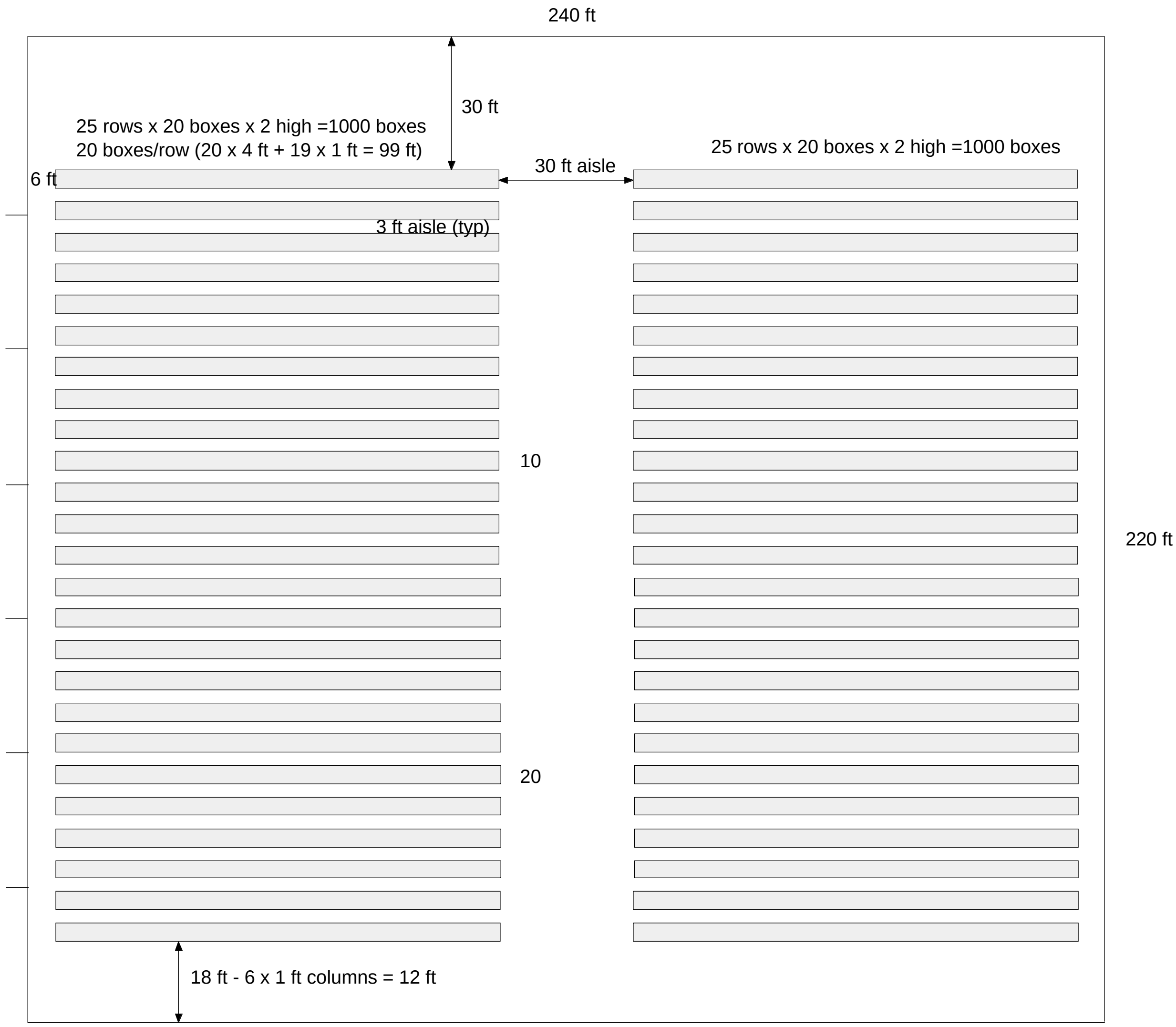


Figure 6.3 Process Building General Arrangement Conversion to UO2 and AHF



Storage provided = 2000 boxes
Storage required for 1 yr = 1926 boxes

Figure 6.4 UO2 Storage Building Plan
Conversion to UO2 and AHF

Activity ID	Activity Description	Orig Dur	Early Start	Early Finish
MILESTONES				
GENERAL				
10	Record of Decision	0		30JUN99*
20	Site Selection	0		30SEP99*
30	Primary Contractor Selection	0		30APR00*
35	DOE Design Review	0		31DEC00
40	Authorize Construction	0		31MAR01
50	PSAR	0		30NOV00*
45	Select Construction Contractor	0		31OCT01
55	FSAR Approved by DOE	0		31OCT03*
60	End of Construction	0		31JAN04*
65	DOE Design/Operation Reviews	0		31JUL04*
70	Start-up & Full Operations	0		31JUL04*
PROJECT MANAGEMENT				
GENERAL				
100	Project Definition	9	01MAY99	31JAN00
105	DOE Procurement Action	9	01AUG99	30APR00
110	Site-Specific EIS	18	01NOV99	30APR01
120	Primary Contrractor Evaluation	3	01FEB00	30APR00
130	Permitting & Licensing	44	01MAY00	31DEC03
DESIGN / ENGINEERING				
GENERAL				
200	Preliminary Design	12	01MAY00	30APR01
400	Detailed Design	24	01NOV00	31OCT02
550	Construction Support	27	01NOV01	31JAN04
PROCUREMENT				
GENERAL				
600	Procurement	33	01MAY01	31JAN04
CONSTRUCTION				
PHASE 1 - PROCESS BUILDING AND SUPPORT BUILDINGS		27	01NOV01	31JAN04
PHASE 2 - STORAGE AREA		15	01MAY02	31OCT03

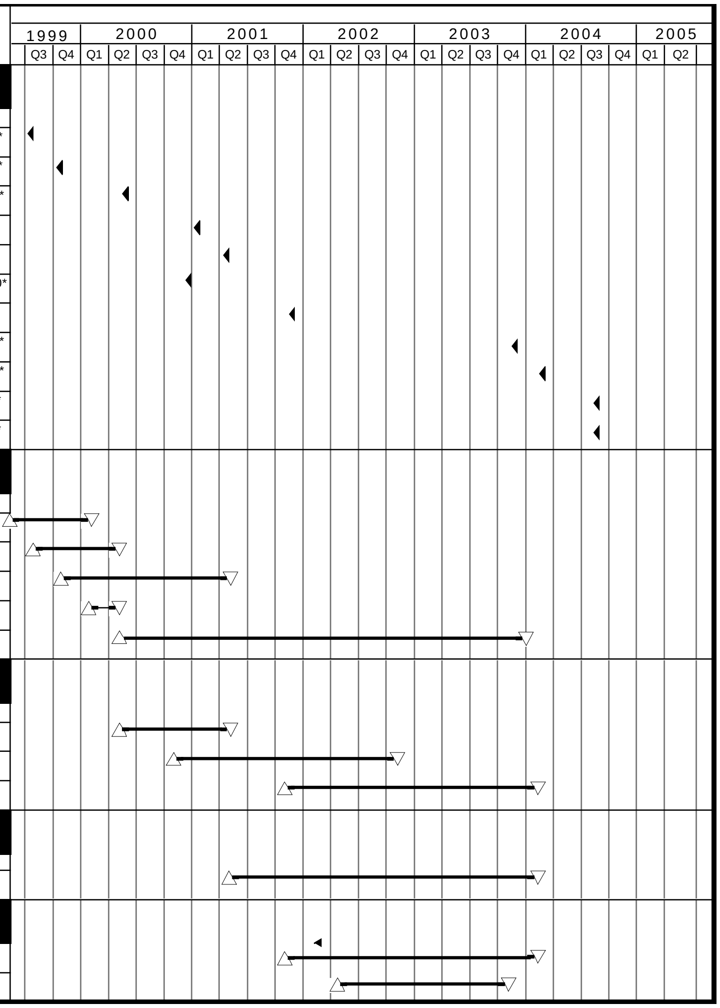


Figure 6.5 UO2/AHF Plant, 25 Year Privately Owned and Operated Preliminary Project Schedule

Table 6.1 Plant Manpower Estimates for UO2/AHF Conversion Facility
25 Years Privately Owned and Privately Operated

Labor Category	Total Employees
Officials and Managers	6
Professionals	10
Technicians	16
Office and Clericals	10
Craft Workers (Maint./Production)	24
Operators	92
Line Supervision	17
Security	16
Total	**191**

Table 6.2 UO2/AHF Project Capital Cost Estimate

Facility/Cost Items	Subtotal	Contingency	Total
Process Equipment	41,874,000	14,656,000	56,530,000
Process Facilities	75,488,000	26,421,000	101,909,000
Balance of Plant	35,348,000	12,372,000	47,720,000
Subtotal	152,710,000	53,449,000	206,159,000
Engineering & Design @14.4%	21,990,000	7,697,000	29,687,000
Total	**174,700,000**	**61,146,000**	**235,846,000**

Table 6.3 UO2 and AHF Operation and Maintenance Cost Estimate

DESCRIPTION	TOTAL ANNUAL COST ($)
1. Consumable and Materials	
Process Chemicals	613,555
Cooling Tower Water Treatment Chemicals	30,104
Product and Waste Containers	2,990,006
Scheduled Replaceable Equipment for Reaction Chambers	771,680
Facility Maintenance	755,073
Equipment Spares	1,130,600
Total Materials	**6,291,017**
2. Utilities & Service	
Total Utilities	**1,897,729**
3. Labor	
Plant operation labors	16,944,008
Off-site overhead labor	2,033,281
Total Labor	**18,977,289**
4. Waste Management & Disposal	
Low Level Wastes	1,269,500
Mixed Low Level Wastes	4,100
Hazardous Wastes	5,180
Total Waste Management/Disposal	**1,278,780**
Total Operation & Maintenance Annual Cost	**28,444,815**
Start-Up Cost Facility start-up cost based on allowance of 65% of one year O&M total labor cost.	**12,335,238**
Total O&M Cost for 25 years	**723,455,609**

Table 6.4 Expenditure Funding Profile
UO2/AHF 25 Years POPO
10-year payback
(in million FY2000 dollars)

	TOTAL	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09
Construction Investment:												
NEPA/Licensing	5.0		0.5	1.3	1.3	1.3	0.5					
Engineering	29.7		3.7	13.7	9.2	2.7	0.4					
Construction	206.2	0.2	2.0	6.0	39.7	122.6	35.7					
Start-up	12.3						12.3					
Total Investment Loan	253.2	0.2	6.1	21.0	50.2	126.7	49.0					
Accumulated Debt:		0.2	6.9	30.3	87.3	232.2	305.0	284.5	262.2	238.0	211.7	183.2
Operation Expenses:												
Debt Payment	464.9							46.5	46.5	46.5	46.5	46.5
Operation & Maintenance	711.1						4.7	28.4	28.4	28.4	28.4	28.4
Decon &Decommission	23.6											
Total Operation Expenses	1199.6						4.7	74.9	74.9	74.9	74.9	74.9
Revenues:												
Break-even Conversion Revenue	971.0						11.1	66.4	66.4	66.4	66.4	66.4
HF Product Sales	228.6						1.5	9.1	9.1	9.1	9.1	9.1
Total Revenue	1199.6						12.6	75.6	75.6	75.6	75.6	75.6
Cash Funding Requirements:	759.3	0.2	6.1	21.0	50.2	126.7	52.2	19.3	19.3	19.3	19.3	19.3
Break-even Government Payment:	971.0						11.1	66.4	66.4	66.4	66.4	66.4

Notes: Cash funding requirements reflect cash flow required for construction and operating minus revenue from AHF sales. Break-even government payment is the funding from DOE paid to the private plant owner for the conversion service to cover the break-even cost for construction loan payment, operation, and D&D only; no profits included.

Assumptions:

Loan Interest Rate @ 8.5% for Construction Loan during construction period
Loan Interest Rate @ 8.5% for payback in 10 years at start of operation

Chemical Sale Price: 70 ¢/lb of HF

Table 6.4, continued Expenditure Funding Profile
UO2/AHF 25 Years POPO
10-year payback
(in million FY2000 dollars)

	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
Construction Investment:													
NEPA/Licensing													
Engineering													
Construction													
Start-up													
Total Investment Loan													
Accumulated Debt:	152.3	118.7	82.3	42.8	0.0								
Operation Expenses:													
Debt Payment	46.5	46.5	46.5	46.5	46.5								
Operation & Maintenance	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4
Decon &Decommission													
Total Operation Expenses	74.9	74.9	74.9	74.9	74.9	28.4	28.4	28.4	28.4	28.4	28.4	28.4	28.4
Revenues:													
Break-even Conversion Revenue	66.4	66.4	66.4	66.4	66.4	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9
HF Product Sales	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Total Revenue	75.6	75.6	75.6	75.6	75.6	29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1
Cash Funding Requirements:	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3
Break-even Government Payment:	66.4	66.4	66.4	66.4	66.4	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9

Table 6.4, continued Expenditure Funding Profile
UO2/AHF 25 Years POPO
10-year payback
(in million FY2000 dollars)

	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32
Construction Investment:										
NEPA/Licensing										
Engineering										
Construction										
Start-up										
Total Investment Loan										
Accumulated Debt:										
Operation Expenses:										
Debt Payment										
Operation & Maintenance	28.4	28.4	28.4	28.4	28.4	28.4	23.7			
Decon &Decommission								11.8	11.8	
Total Operation Expenses	28.4	28.4	28.4	28.4	28.4	28.4	23.7	11.8	11.8	
Revenues:										
Break-even Conversion Revenue	19.9	19.9	19.9	19.9	19.9	19.9	16.6			
HF Product Sales	9.1	9.1	9.1	9.1	9.1	9.1	7.6			
Total Revenue	29.1	29.1	29.1	29.1	29.1	29.1	24.2			
Cash Funding Requirements:	19.3	19.3	19.3	19.3	19.3	19.3	16.1	11.8	11.8	
Break-even Government Payment:	19.9	19.9	19.9	19.9	19.9	19.9	16.6			

7. Preliminary Case Study: DUF6 Conversion to U3O8/CaF2

7.1 Introduction

About 700,000 metric tons (MT) of depleted uranium hexafluoride (DUF6) are currently stored at the Paducah, Portsmouth and Oak Ridge sites. Public Law 105-204 requires the DOE to submit to Congress a plan to ensure that all funds accrued on the books of USEC for disposition of DUF6 will be used for the construction and operation of plants to treat and recycle the DUF6. The Department of Energy's Initial Plan calls for construction to begin in the year 2002 time frame.

For this preconceptual design project, the preliminary case study, to examine the cost and issues involved in a 2002 time frame for construction start was based on a conversion plant using a dry process to convert DUF6 to uranium oxide (U3O8) and calcium fluoride (CaF2) as final products. The process selected to study involves least process equipment and byproduct streams. The construction and operation of the conversion plant is based on a government owned and contractor operated facility in conformance with DOE standards and operating for 25 years.

A preconceptual plant design, rough cost estimate, and preliminary project schedule were developed. The integrated conversion plant includes capabilities for DUF6 cylinder preparation, conversion of DUF6 to uranium oxide and fluorine byproducts, empty cylinder treatment for disposal, and interim storage for oxide and byproducts.

Significant design bases for the conversion plant include:

- The plant will convert DUF6 to U3O8 by a dry process. Hydrogen fluoride (HF) off-gas will be treated to produce solid CaF2.

- The plant capacity will be based on a 25 year operating period to process DUF6 inventory of 36,910 cylinders (450,000 MT DUF6).

- Storage will be provided for one year production of U3O8 and CaF2 product.

- The U3O8 and CaF2 products are retained by the DOE for other uses or disposal.

- To bound costs associated with empty cylinders, assume all empty cylinders will be washed, compacted, and returned to the DOE for disposal.

- The plant will be on a DOE owned site at or near a gaseous diffusion plant and include the support facilities and infrastructures/utilities needed for a greenfield facility.

- The design will consider addition of future process and storage buildings.

7.2 Summary of Results

The plant annually processes 18,000 MT of UF6 contained in 1,476 cylinders to produce 14,352 MT of U3O8, 11,966 MT of CaF2, and 2,000 MT of empty cylinder metal waste. The plant, which includes a one year storage capacity for U3O8 and CaF2, occupies about 36 acres. Additional storage capacity would require about 5 acres for each year of additional U3O8 storage or CaF2 storage.

The construction capital cost estimate is $187 million for the plant facilities. The engineering cost is about $34 million. Each year of additional storage would be $22 million for U3O8 and $18 million for CaF2. These costs are in 1st Quarter FY2000 dollars.

The annual operation and maintenance (O&M) cost is about $31 million. The O&M cost does not include disposal of empty cylinder metal. Cost for NEPA, regulatory and licensing activities is estimated at $5 million. Decontamination and decommissioning (D&D) cost is estimated at $22 million.

The preliminary schedule assumes selection of an A/E contractor by June 2000. The schedule shows plant engineering design starting in July 2000, construction beginning in April 2002, plant completion in June 2004, and full operation beginning in December 2004. Peak engineering personnel is 80 persons and peak employment during construction is about 430 persons. Plant employment during operations is 193 persons.

The 2002 construction start depends on the key milestone dates for site selection, selection of primary contractor and construction contractor, and construction approval. The schedule includes NEPA activities, as a site-specific EIS is required, and DOE regulatory activities. The amount of U3O8 and CaF2 storage provided affects cost and may need additional study. Process design criteria for UF6 cylinder vaporization, conversion reaction chamber, HF distillation, and empty cylinder treatment are necessary to ensure successful facility design and operation.

7.3 Conversion Process Description

Depleted uranium hexafluoride (DUF6) is processed to produce uranium oxide (U3O8) and calcium fluoride (CaF2). The average throughput is 5 cylinders per day
(5,670 lb/hr DUF6) based on 80% plant availability (7,000 hours/yr or 292 days/yr). The process block flow diagram is shown in Figure 7.1.

The DUF6 is shipped by truck from the cylinder yards at the gaseous diffusion plant (GDP) to an outdoor storage pad at the Conversion Facility. The cylinder is moved into the Process Building for inspection and preparation. The cylinders are loaded into steam-heated autoclaves to vaporize the DUF6 for feeding into the conversion process. Cylinders with questionable integrity are loaded into hot air ovens where the solid DUF6 sublimes into a gas under vacuum. This avoids melting the DUF6 and pressurizing the cylinder, which occurs when using an autoclave. Several of the cylinders may be substandard based on the DUF6 Engineering Analysis Report (p. 6.1-4-5).

The DUF6 gas is mixed with steam, nitrogen and hydrogen and converted to U3O8 in a series of two reaction chambers. The chemical reactions are:

$UF6 + 2\ H_2O \text{ ---> } UO2F_2 + 4\ HF$

$3\ UO2F_2 + 3\ H_2O \text{ ---> } U3O8 + 6\ HF + 0.5\ O_2$

$H2 + 0.5\ O_2 \text{ ---> } H_20$

Four reaction lines are provided to meet the required throughput. The U3O8 product is cooled, compacted with a rotary compactor to increase its bulk density, and packaged in metal bins. The 100 cu ft bins are about 4x4x7 (height) ft and hold 9 tons (8.16 MT) of U3O8. The filled bins are transferred to the U3O8 Storage Building.

Reaction chamber off-gas containing HF, excess steam, and nitrogen is filtered to remove uranium particulates. The off-gas flows to the HF absorption columns, where the HF and steam are condensed and an aqueous HF solution is produced. The HF solution is neutralized with slaked lime according to the reaction:

$2\ HF + Ca(OH)_2 \dashrightarrow CaF2 + 2\ H_2O$

The resulting CaF2 precipitate is separated by filtering, washed with water, dried and loaded into bins. The 4x4x7 ft, 100 cu ft bins, which hold 5 tons (4.54 MT) of CaF2, are transferred to the CaF2 Storage Building. The CaF2 is expected to contain less than 1 ppm uranium.

Off-gas from the absorption columns flows to the scrubber system. Residual HF in the off-gas is removed by scrubbing with a potassium hydroxide solution. The off-gas is then HEPA filtered and discharged to the atmosphere.

After vaporization, the empty cylinders are transferred to an outdoor pad and stored for three months. This allows for radioactive decay of non-volatile daughter products in the cylinder. The cylinders are then brought into the Process Building, washed with water, crushed, and loaded into boxes for disposal as LLW. Each 6x14x3 (height) ft box contains about 9,000 lb of metal from three crushed cylinders. A special cylinder handling fixture is provided for cylinders with questionable wall strength. The cylinder wash effluents are fed into the main conversion processes.

The process materials and annual quantities are summarized below:

Major Input Streams	**Major Output Streams**
Depleted Uranium Hexafluoride 18,000 MT/yr 1476 cylinders/yr	Uranium Oxide (U3O8) 14,352 MT/yr 1758 4x4x7 (H) ft bins/yr (18,000 lb/bin) or 24,344 55-gal drums/yr (1300 lb/drum)
Lime (CaO) 8505 MT/yr 312,600 ft3/yr	Calcium Fluoride (CaF2) 11,966 MT/yr 2639 4x4x7(h) ft boxes/yr (10,000 lb/drum)
Hydrated Lime Ca(OH)2 113 MT/yr 4100 ft3/yr	Empty Cylinder Metal Waste 2000 MT/yr 492 6x14x3(h) ft boxes/yr (9000 lb/box)
Ammonia (NH3) 193 MT/yr 84,000 gal/yr	

Major process equipment includes four steam autoclaves, six hot air ovens, four reaction chamber lines, U3O8 compaction and bin loading system, off-gas scrubbing system, HF absorption and neutralization, CAF2 drying and bin loading, two empty cylinder washing machines, and one cylinder crusher.

7.4 Conversion Plant Description

The Conversion Facility is assumed to be constructed on a DOE site at a greenfield location at or near the gaseous diffusion plants. The Conversion Facility occupies about 36 acres. Additional storage buildings for U3O8 and CaF2 could be built adjacent or at a nearby location. Each additional one year increment of U3O8 or CaF2 storage occupies about 5 acres. A conceptual site plan for the Conversion Facility is shown in Figure 7.2.

The Conversion Facility includes full and empty cylinder storage pads, the Process Building, a U3O8 Storage Building, a CaF2 Storage Building, a Waste Storage Building, and support facilities. The site plan considers addition of future process facilities such as uranium metal, sintered uranium pellets, or anhydrous HF production.

The Conversion Facility will be designed and constructed in compliance with DOE Orders and applicable regulations and codes, and will meet the intent of NRC standards. In general, a graded approach as established in DOE Order 420.1 is used for the design of all structures, systems, and components (SSC) in the plant facilities. All SSC's will be assigned a Natural Phenomena Performance Category using the criteria in the DOE Standards DOE-STD-1020-94 and DOE-STD-1021-93 during the design phase.

In the absence of a hazard analysis, it is assumed that the Process Building is performance category PC-3 to control and confine hazardous material. The building structure is reinforced concrete construction in the processing areas. The remainder of the building housing the personnel support area is steel frame, metal siding construction. The Process Building is 30 ft high in the processing areas and 18 ft high in the support areas. HVAC equipment is located on a mezzanine level. The process room air is filtered through one stage of HEPA filters prior to discharge to atmosphere. The Process Building general arrangement is shown in Figure 7.3.

The U3O8 Storage Building and CaF2 Storage Building have a one year capacity. The U3O8 Building holds 1,760 bins stacked one high, and the CaF2 Building holds 2,640 bins stacked two high. The Waste Building has a one month capacity for staging treated empty cylinders and process waste for transport offsite. The U3O8, CaF2, and waste storage buildings are assumed PC-2 to maintain storage function after the occurrence of a natural phenomena hazards event. These buildings are steel frame and concrete clad panel construction and are ventilated and lighted, but no heating, cooling or HEPA filtration is provided. Access aisles allow personnel to inspect the bins during storage. A general storage arrangement in the U3O8 Building is shown in Figure 7.4. A storage arrangement for the CaF2 Building is shown in Figure 7.5.

Plant operations are assumed to be continuous for 24 hours/day, 7 days/week, 52 weeks/year. Due to seven day per week operation, a fourth shift is necessary to account for normal days off for employees. The number of employees during operation is estimated to be 193 persons, with 70 employees on day shift and 41 each of the other three shifts. The numbers are estimated based on process operation labor and facility support labor requirements needed to operate the plant. No allowance is included for plant medical or fire fighting personnel. A breakdown of the plant operation employees by category and by shift is shown in Table 7.1.

7.5 Cost Estimate

The cost estimates are rough order of magnitude estimates based on a preconceptual level design information. The cost estimate results are summarized below:

	Cost ($million)	Contingency ($million)	Total Cost ($million)
Conversion Facilities			
Engineering	--	--	34
Plant Facilities Construction Cost	138	49	187
Startup Cost	--	--	13
Annual Operations and Maintenance Cost (O&M)	--	--	31
Decontamination and Decommissioning (D&D)	--	--	22
Additional Storage			
Engineering	--	--	3.2
U3O8 Storage (1 yr capacity) Capital Cost	19	3	22
CaF2 Storage (1 yr capacity) Capital Cost	16	2	18
NEPA/Licensing	--	--	5

The estimates do not include costs for plant design criteria development, cost of land, site qualifications, or extension of local roads and utility lines to the site boundary. The estimates take into account the procurement pricing, labor productivity, and indirect cost factors for a government project. Cost estimate bases are described in the Appendix.

The construction capital costs are based on an engineering, procurement and construction management (EPCM) approach. Capital costs, see Table 7.2, are reported in 1st quarter fiscal year 2000 dollars (October 1999). Labor costs are based on local wage rates at a generic gaseous diffusion plant located in mid-U.S.A. The capital cost estimate utilized historical cost data, estimating manuals, allowances and budgetary quotations. A 35% contingency was applied to the capital costs for the Conversion Facility and 15% for the subsequent Storage Facilities. These contingency levels are based on previous risk analysis on projects of similar scope and level of design details. Engineering cost was estimated at 18% of the capital costs for the Conversion Facility and 8% for the subsequent Storage Facilities. The lower percentages are used for the subsequent Storage Facilities because previous building engineering design can be reused. Product and wastes container costs are included in the O&M costs. The D&D cost was estimated as 10% of the capital cost.

The O&M cost includes costs for materials, utilities, labor, waste disposal, and management and operation (M&O) contractor fees, see Table 7.3. Plant startup cost was assumed to be 65% of the annual O&M labor cost. The annual O&M cost does not include the cost for disposal of empty cylinder metal waste. If the empty cylinder metal is to be disposed as low-level waste (LLW), the estimated disposal cost would range from $1 million to $12 million annually, depending on the disposal sites. Revenue from sales of CaF2 is also not included in the O&M cost. If the CaF2 is sold, the estimated annual savings could be based on CAF2 revenue and reuse of bins.

The annual expenditure required to support the construction and operation of the conversion plant in the initial project years is shown in Table 7.4 The expenditure profile for all years is shown below. The expenditure profiles are derived from loading the estimated capital and operating costs onto the project schedule. A constant FY2000 dollar value is used in the expenditure outlay because of the difficulty in accurately projecting the inflation rate for future years.

7.6 Project Schedule

An estimated preliminary project schedule is shown in Figure 7.6. The schedule allows 3 years for Title I and II design and 2 years for construction. The schedule is based on a fast track premise with overlapping engineering phases and early procurement of some equipment (most equipment is available in 12-18 month lead time) and a two-phase construction plan. The estimated peak engineering personnel is 80 persons and peak employment during construction is 430 persons.

7.7 Discussion and Issues

7.7.1 Process

Bins were used to package the U3O8 because of the space savings compared to 55-gallon drums. Using bins instead of drums reduces the storage building area by about 35%. Additional study is needed to determine the best storage container to use with the cost considerations on facilities and transport.

The CaF2 product is not a hazardous waste, but CaF2 powder is a health hazard and containment is required during handling. Packaging the CaF2 in sealed bins is appropriate for both long-term storage or transport to customers. Other methods of handling the CaF2 include bulk storage in vaults or silos and shipment in rail hopper cars or tank trucks.

In cylinder washing, the empty cylinders are cleaned to remove the reactive fluoride materials inside the cylinder. It was assumed that the metal from washed empty cylinders is returned to the DOE for disposal. The residual uranium contaminated cylinders might require the cylinder metal to be disposed of as LLW. Alternate dispositions include recycling and reusing the radioactively-contaminated carbon steel for LLW containers for further use in the nuclear industry, or decontaminating the metal sufficiently for disposal as non-hazardous waste or scrap.

The purity of the calcium oxide (CaO, quicklime) fed to lime slaking and used to neutralize the HF affects the purity of the CaF2 product. Typical high calcium quicklime contains up to 5% impurities (mainly MgO and $CaCO_3$), which could end up in the CaF2 product. If this impurity is objectionable, high purity calcium oxide could be used.

7.7.2 Facility

Buildings for processing and storage were assumed to be performance category PC-2 or PC-3. A safety and accident analysis was not performed and is needed to determine the hazard classification and performance category. The appropriate structure, confinement and ventilation for buildings housing large quantities of U3O8 needs study.

The DUF6 Engineering Analysis Report has identified issues with federal (49CFR173.420) or ANSI N14.1 transportation requirements and overpressured, overfilled or substandard cylinders. The Report suggests that a new overpack be designed and licensed if filled substandard cylinders must be shipped from off-site. The cost of overpacks is not considered in the report. This transportation issue still needs to be resolved.

The preconceptual plant design is essentially a single line plant. Multiple autoclaves, ovens, and conversion reaction chambers are provided to obtain the design throughput. The reaction chamber off-gas and CaF2 systems are single line systems with installed spares on maintenance-prone items such as pumps and filters. A RAM (reliability, availability, maintainability) analysis would determine if this configuration is satisfactory and whether independent parallel lines might be desirable.

7.7.3 Cost Estimate

The cost estimate is based on a government owned and contractor operated plant located on a government facility site. The major contributors to the capital cost are the Process Building including the structure and service systems. The major process equipment costs are the cylinder handling crane, autoclaves, hot air ovens and DUF6 compressors, conversion reaction chambers, and cylinder tilt and roll wash stands. The cost to dispose of empty cylinder metal is not included in this report. If it is disposed as LLW, the disposal cost could be significant.

7.7.4 Schedule

The schedule shows a construction start early in the second quarter of year 2002. This appears to be attainable if the site selection, selection of contractor, and early approval for construction dates are met. The Record of Decision is expected to be issued by the end of June.

7.7.5 Production Criteria

This case study assumes the government develops its own processes, rather than using pre-existing processes owned by private companies.

Production criteria for conversion facility are required for plant design. Major areas of the conversion process requiring criteria verification include:

The DUF6 to U3O8 conversion requires data on reaction chamber size and details, operating conditions, and off-gas particulate removal.

The calcium fluoride process requires selection and sizing the filtration and drying equipment.

Empty cylinder treatment entails characterizing the wash effluents and confirming they can be fed into the main conversion process.

The DUF6 vaporization rate from a large cylinder in a hot air oven needs to be determined.

Methods to determine whether a cylinder is in good condition and suitable for autoclave vaporization.

Depending on the availability of process data, establishment of design criteria might require literature survey, laboratory studies, or pilot plant demonstration.

7.8 References

Initial Plan for the Conversion of Depleted Uranium Hexafluoride, as Required by Public Law 105-204, U.S. Department of Energy, 1999

Draft Engineering Analysis Report for the Long-Term Management of Depleted Uranium Hexafluoride, UCRL-AR-124080, Lawrence Livermore National Laboratory, May 1997

Uranium Hexafluoride: A Manual of Good Handling Practices, ORO-651, U.S. Department of Energy, October 1991

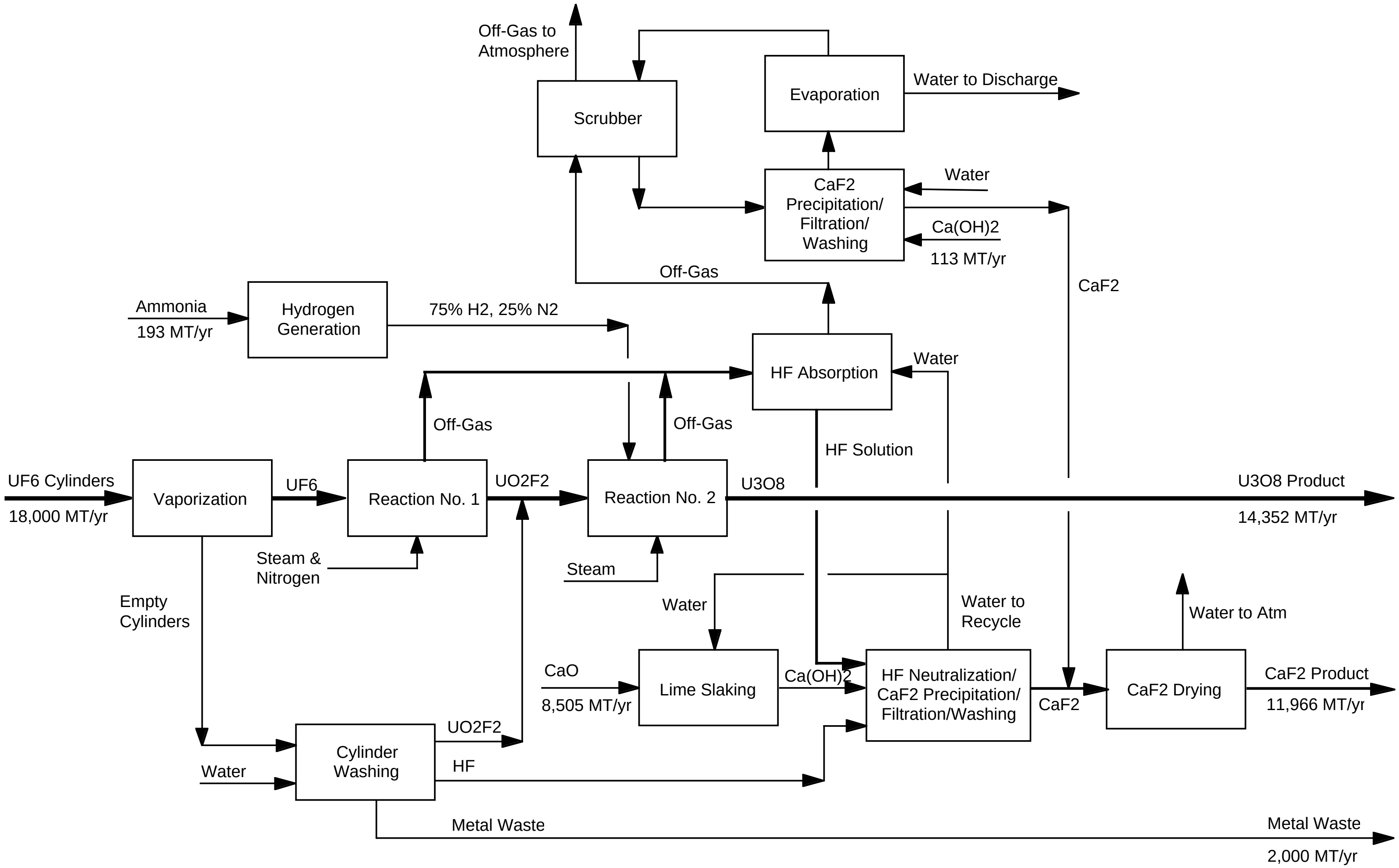


Figure 7.1 Process Block Flow Diagram
Conversion to U3O8 and CaF2

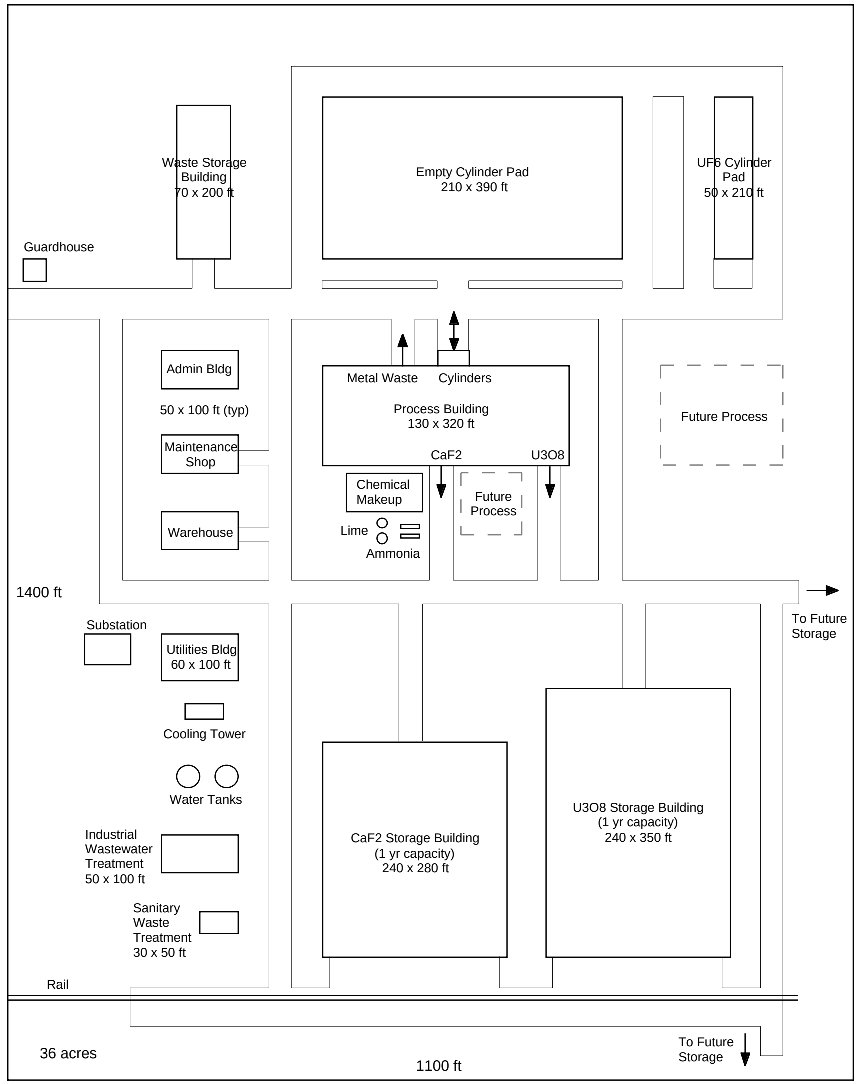


Figure 7.2 Site Plan
Conversion to U3O8 and CaF2

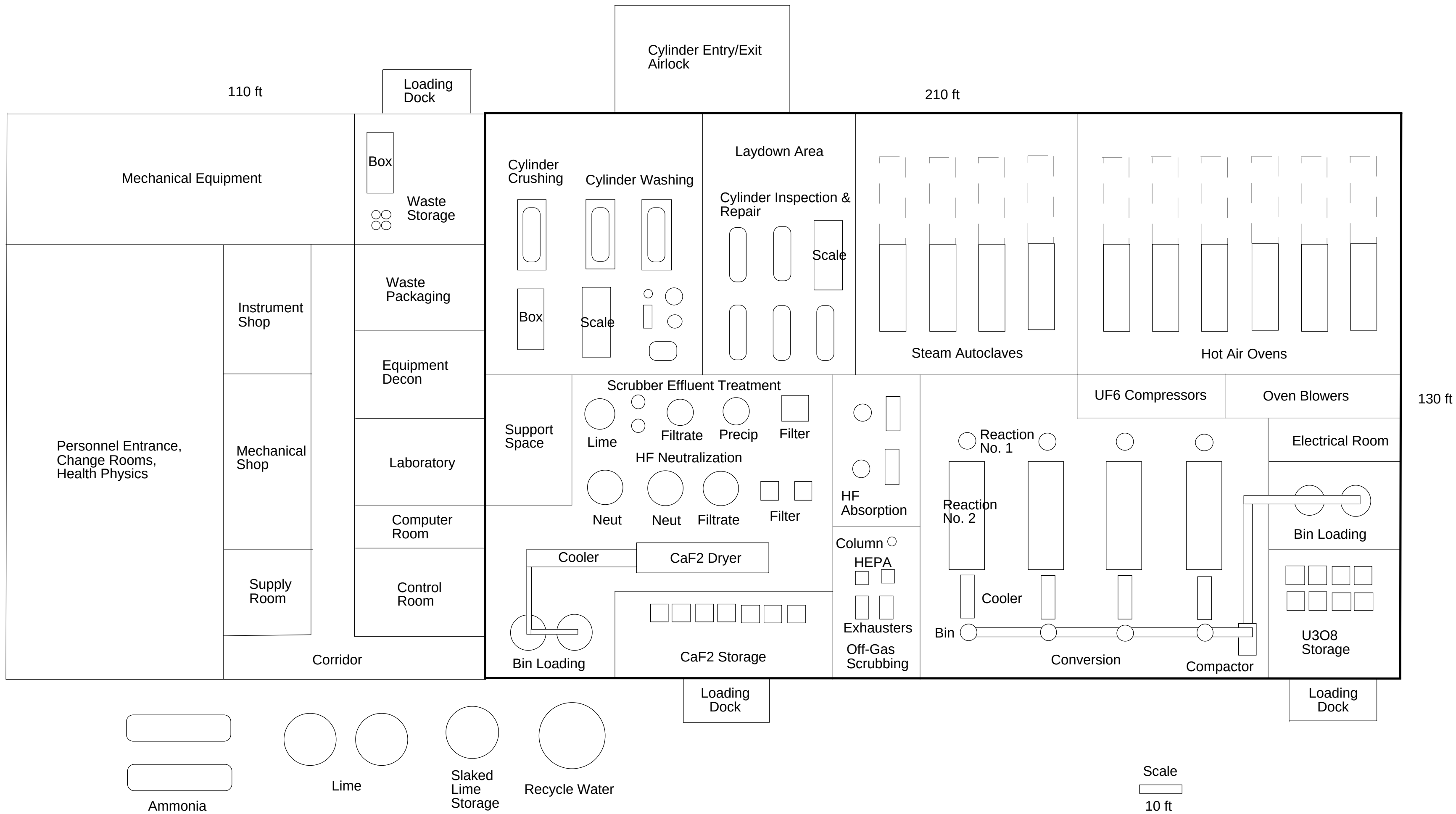


Figure 7.3 Process Building General Arrangement Conversion to U3O8 and CaF2

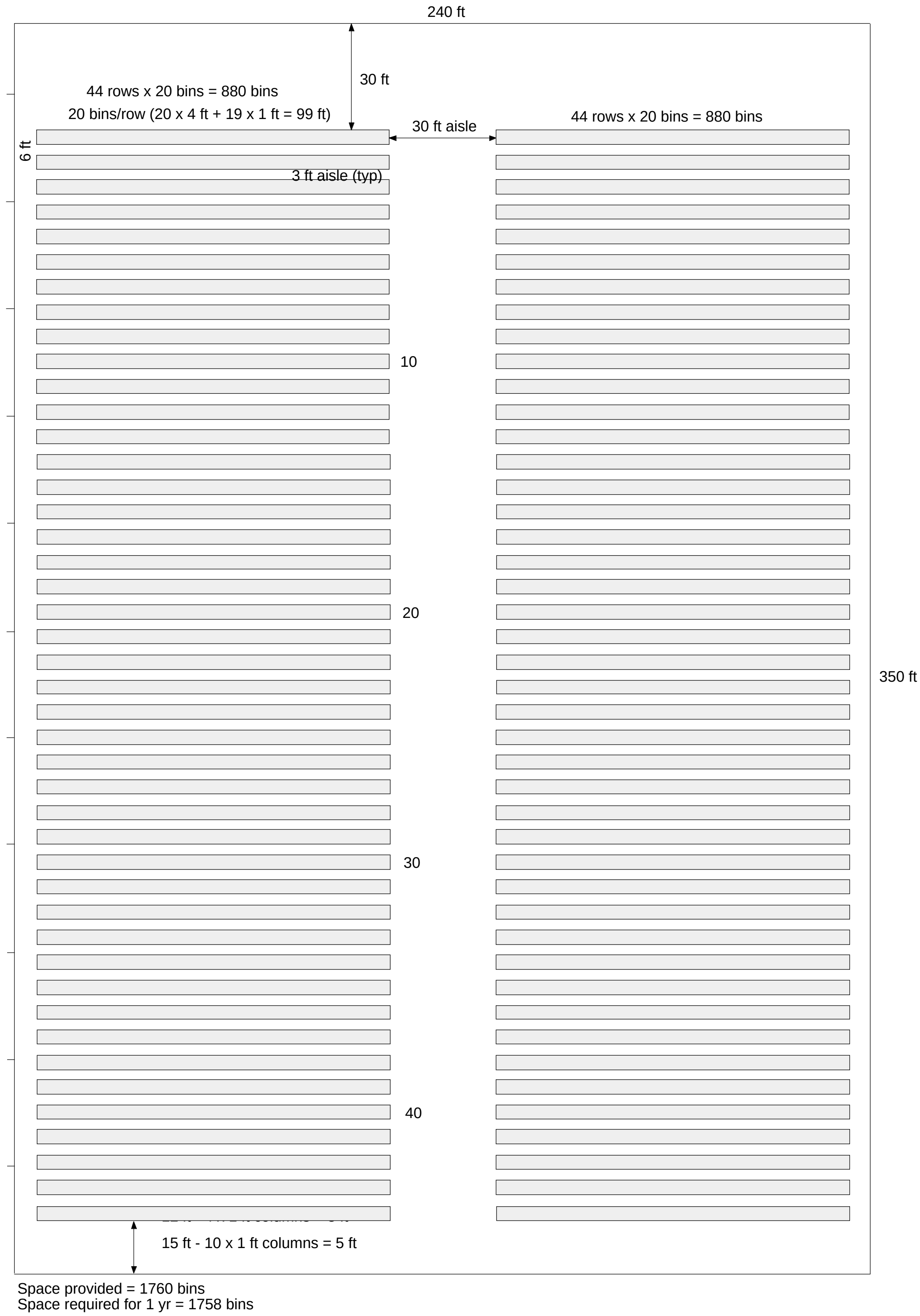
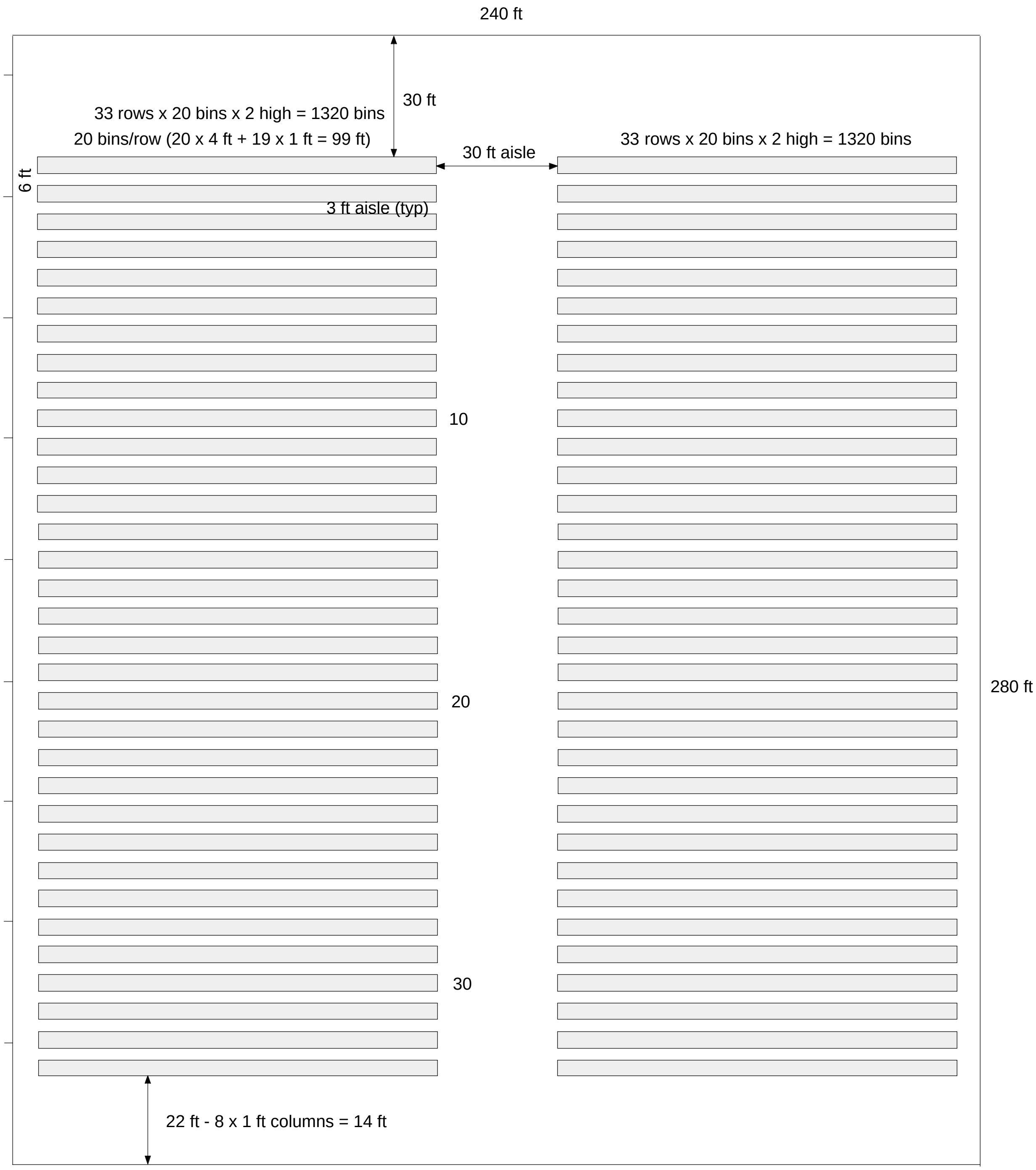


Figure 7.4 U3O8 Storage Building Plan
Conversion to U3O8 and CaF2



Space provided = 2640 bins
Space required for 1 yr = 2639 bins

Figure 7.5 CaF2 Storage Building Plan
Conversion to U3O8 and CaF2

Activity ID	Activity Description	Orig Dur	Early Start	Early Finish
MILESTONES				
GENERAL				
10	Record of Decision	0		30JUN99*
20	Site Selection	0		30SEP99*
30	Select A/E	0		30JUN00*
35	DOE Design Review	0		30JUN01
40	Authorize Construction	0		30SEP01
50	PSAR	0		30APR01*
45	Select Construction Contractor	0		31MAR02*
55	FSAR Approved by DOE	0		30JUN04*
60	End of Construction	0		30JUN04*
65	DOE Design/Operation Reviews	0		31DEC04*
70	Start-up & Full Operations	0		31DEC04*
PROJECT MANAGEMENT				
GENERAL				
100	DOCDR	6	01JUL99	31DEC99
105	A/E Proposal/Selection	6	01JAN00	30JUN00
110	Site-Specific EIS	18	01NOV99	30APR01
130	Permitting & Licensing	48	01JUL00	30JUN04
DESIGN / ENGINEERING				
GENERAL				
200	Preliminary Design	12	01JUL00	30JUN01
400	Detailed Design	24	01JUL01	30JUN03
550	Construction Support	27	01APR02	30JUN04
PROCUREMENT				
GENERAL				
600	Procurement	33	01OCT01	30JUN04
CONSTRUCTION				
PHASE 1 - PROCESS BUILDING AND SUPPORT BUILDINGS		27	01APR02	30JUN04
PHASE 2 - STORAGE AREA		18	01OCT02	31MAR04

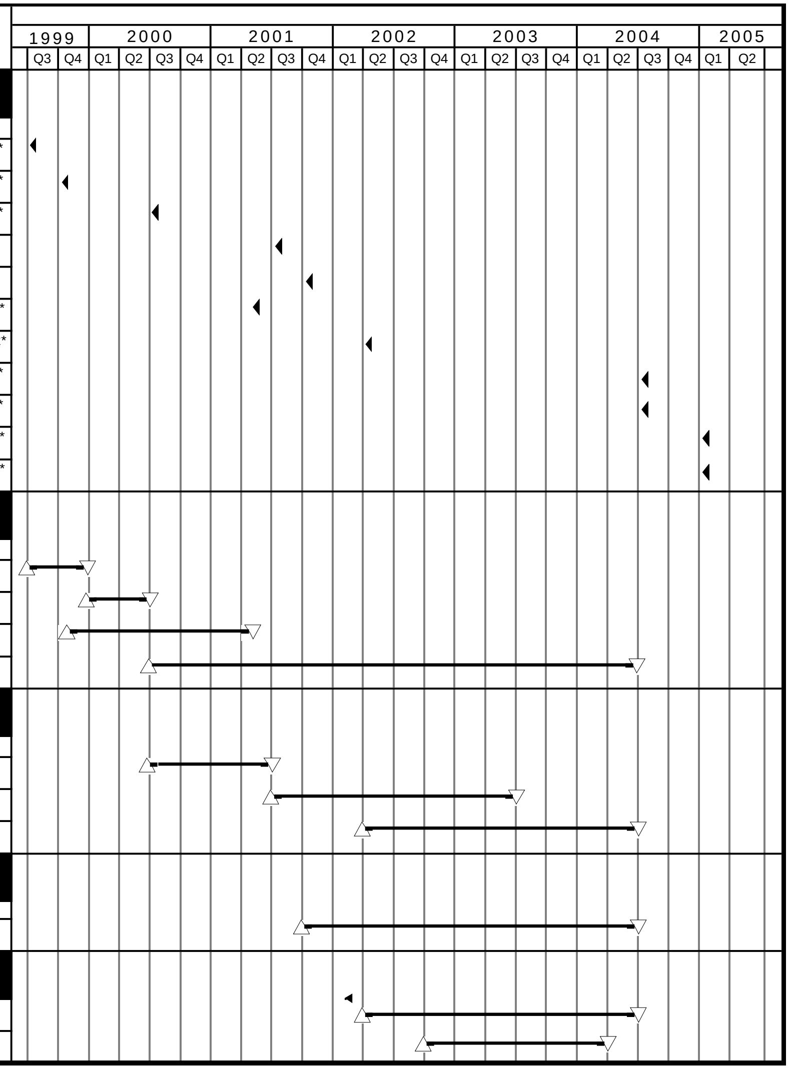


Figure 7.6 U3O8/CaF2 Plant, 25 Year Government Owned and Contractor Operated Preliminary Project Schedule

Table 7.1 Plant Operation Manpower Estimates for U3O8/CaF2 Conversion Facility 25 Years Government Owned and Contractor Operated

Labor Category	Total Employees
Officials and Managers	6
Professionals	10
Technicians	16
Office and Clericals	12
Craft Workers (Maint./Production)	24
Operators	84
Line Supervision	17
Security	24
Total	**193**

Table 7.2 U3O8/CaF2 Project Capital Cost Estimate

Facility/Cost Items	Subtotal	Contingency	Total
Process Equipment	33,283,000	11,649,000	44,932,000
Process Facilities	71,070,000	24,875,000	95,945,000
Balance of Plant	33,996,000	11,898,000	45,894,000
Subtotal	138,349,000	48,422,000	186,771,000
Engineering & Design @14.4%	24,903,000	8,716,000	33,619,000
Total	**163,252,000**	**57,138,000**	**220,390,000**

Table 7.3 U3O8/CaF2 Operation and Maintenance Cost Estimate

DESCRIPTION	TOTAL ANNUAL COST ($)
1. Consumable and Materials	
Process Chemicals	667,604
Cooling Tower Water Treatment Chemicals	33,655
Product and Waste Containers	6,058,285
Scheduled Replaceable Equipment for Reaction Chambers	771,680
Facility Maintenance	641,915
Equipment Spares	898,640
Total Materials	**9,071,779**
2. Utilities & Service	
Total Utilities	**1,925,953**
3. Labor	
Plant operation labors	17,196,012
Off-site overhead labor	2,063,521
Total Labor	**19,259,533**
4. Waste Management & Disposal	
Low Level Wastes	424,500
Mixed Low Level Wastes	4,100
Hazardous Wastes	5,180
Total Waste Management/Disposal	**433,780**
Subtotal Operation & Maintenance Annual Cost	**30,691,046**
M&O Contractor Fees (2%)	**613,821**
Total Operation & Maintenance Annual Cost	**31,304,867**
Start-Up Cost Facility start-up cost based on allowance of 65% of one year O&M total labor cost.	**12,518,697**
Total O&M Cost for 25 years	**795,140,365**

Table 7.4 Expenditure Funding Profile
U3O8/CaF2 25 Years GOCO
(in million FY2000 dollars)

	TOTAL	FY99	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09
NEPA/Licensing	5.0		0.5	1.3	1.3	1.3	0.6					
Engineering	33.6		4.1	15.5	10.4	3.1	0.5					
Construction	186.8	0.2	2.0	6.0	33.5	84.5	60.6					
Total Capital Cost:	225.4	0.2	6.6	22.8	45.2	88.9	61.7					
Startup	12.5						12.5					
Operations	782.6							23.5	31.3	31.3	31.3	31.3
Decon &Decommission	22.0											
Total Operation Cost:	817.2						12.5	23.5	31.3	31.3	31.3	31.3
Revenue from Chemical Sale:	-											
Total Budget Outlay:	1042.6	0.2	6.6	22.8	45.2	88.9	74.2	23.5	31.3	31.3	31.3	31.3

Table 7.4, continued Expenditure Funding Profile
U3O8/CaF2 25 Years GOCO
(in million FY2000 dollars)

	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
NEPA/Licensing													
Engineering													
Construction													
Total Capital Cost:													
Startup													
Operations	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3
Decon &Decommission													
Total Operation Cost:	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3
Revenue from Chemical Sale:													
Total Budget Outlay:	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3

Table 7.4, continued Expenditure Funding Profile
U3O8/CaF2 25 Years GOCO
(in million FY2000 dollars)

	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32
NEPA/Licensing										
Engineering										
Construction										
Total Capital Cost:										
Startup										
Operations	31.3	31.3	31.3	31.3	31.3	31.3	31.3	7.8		
Decon &Decommission									11.0	11.0
Total Operation Cost:	31.3	31.3	31.3	31.3	31.3	31.3	31.3	7.8	11.0	11.0
Revenue from Chemical Sale:										
Total Budget Outlay:	31.3	31.3	31.3	31.3	31.3	31.3	31.3	7.8	11.0	11.0

Appendix: Preconceptual Cost Estimate Bases and Details

Capital Cost Estimate Basis

Process equipment

The process equipment estimate is based on the equipment list in the preconceptual design. They are priced using previous estimates for similar equipment as a guide, current estimating manuals, and in-house data bases.

Process Facilities

The Process Facilities include the Process Building and the Product Storage Buildings. Building quantities are quantified take-offs from the conceptual sketches.

Process Building

The Process Building consists of both reinforced concrete and structural steel structure. Most of the process building is "special construction" with "standard construction" support areas as shown on the sketches in the scope figures.

U3O8, UO2, and CaF2 Storage Buildings

The applicable U3O8, UO2, and CaF2 Storage Buildings are steel frame structures with concrete clad panel wall and metal deck/concrete roofing.

AHF Storage Building

The applicable AHF Storage Building is a reinforced concrete building.

Site and Balance of Plant

Balance of plant includes the site improvements and utilities, and the support buildings.

The site is assumed level site with ground characteristics suitable for facility construction and easy access for construction activities. Site includes DUF6 cylinder concrete storage pad and empty cylinder concrete storage pad with steel saddles.

The yard mechanical includes cooling towers, domestic water, service water and fire water tanks, and exhaust stack; and yard equipment and cranes are included.

Yard piping systems are based on the rough takeoff from the site sketch and average estimated sizes. It is assumed 75% of these pipes are on pipe rack and 25% are buried.

An electrical substation and duct bank, yard lighting, and ambient air monitors are included.

Support buildings include a waste storage building, administration building, utility building, warehouse building, maintenance shop, industrial waste treatment building, sanitary waste treatment, and entry control building, and others.

U3O8, UO2, and CaF2 Future Storage Facilities (Additional Storage)

Cost estimates for applicable additional storage facilities are similar to above and include standard site preparation, roads, and services. Contingency is assumed at 15% and Engineering Costs are assumed at 8% of Capital Costs.

Quantity development and pricing

Quantities were factored based on building sizing from the estimates for similar facilities, and priced on current pricing levels.

Manual labor

Davis-Bacon manual labor rates for a generic GDP in the Midwest area were used. The Workers' Compensation Insurance rates and SUI rates are included in the wage rates. A standard 40 hour work week was used and an allowance for casual overtime was included by craft.

Initial Spares

100% spares are included for the critical engineered process equipment. Initial spares are included at 5% of the support system mechanical equipment cost.

State Sales Tax

A sales tax of 6% is included for materials and equipment

Distributable (General Conditions), Overhead and Profit costs

Distributable costs include temporary construction facilities, construction equipment, tools, materials, and other distributable support and non-manual labor costs, and field office costs. The distributable costs are factored from direct labor costs at rates based on recent evaluation of private nuclear/industrial rates. POPO cases, or government nuclear projects for GOCO cases.

Contractor's bond is calculated at 2% of total construction cost for POPO cases and 1% for GOCO cases.

Construction contractor's overhead and profit was factored at 5% of the material and subcontractors' cost and 15% of the labor costs.

Construction management

Construction management costs, including the construction manager's overhead and profit, was included at 8% of the construction contractor's costs for POPO cases and 10% for GOCO cases.

Architect-engineering, and procurement

Architect-Engineer's design and construction support costs include all functions such as engineering management, project control, all discipline engineering, documentation, quality control, procurement, and support services. The costs were factored at 14.4% of the field and management costs for POPO cases and 18% for GOCO cases.

Program management

Program management costs are factored at 5.4% of the field costs for POPO cases and 6% for GOCO cases.

Escalation

Costs are at 1st Quarter of FY 2000 level. Escalation beyond 1st Q/FY00 is excluded.

Contingency

Contingencies are allowed at 35% for construction and project management.

Exclusions

1. Cost of land.
2. Roads/rail and utilities outside the project fence line.
3. Research and development costs.
4. Site qualifications.
5. DOE Oversight.
6. Transportation.

Operation and Maintenance Cost Estimate Basis

The operations cost in this estimate is defined as the operation and maintenance costs of the facility over its expected operating life. The operation and maintenance cost for the DUF6 Conversion Plant includes operating personnel wages, utilities, consumables, operation material and maintenance expenditures, and waste management and disposal. M&O contractor fees are also applied to GOCO cases.

Consumable Material Costs

Consumable material costs from process operations such as chemicals and additives are based on quoted costs in Chemical Marketing Prices Report magazines. Cooling tower water system chemical treatment costs are based on a preliminary quote from NALCO Chemical Company for treating the required gallons of make-up water. Product bins are based on quoted costs from Container Products Corporation. Other material costs include supply of waste containers and drums. The costs for the facilities equipment maintenance is based on an allowance of 1% of total equipment capital cost plus 1% of total direct operation and maintenance labor costs. The cost for major capital replacement is based on an allowance of 2% of total facility equipment costs.

Utilities Cost

The operating cost for utilities and services to operate the facilities is estimated using an allowance of 10% of the total labor cost.

Labor Cost

Operation labor costs are based on the plant operating manpower estimate. The rates for the non-manual labor employees including fringe benefits are based on wage rates for a generic Gas Diffusion Plant site. Offsite labor is estimated using an allowance of 12% of the total labor cost.

Waste Management and Disposal Cost

Waste management and disposal costs are estimated based on costs given in the DUF6 Analysis Guidelines (in the Engineering Analysis Report) for unit volumes for treatment and disposal of hazardous, mixed and low level radwaste to a shallow burial site. These costs are for conversion process waste only and not for conversion products.

M&O Contractor Fees

The management and operation (M&O) contractor fees paid to the operating contractor are assumed to be 2% of the annual operating costs for the GOCO cases.

Exclusions

The transportation of waste out of the facility is excluded from the O&M cost estimate. Cost for disposal of empty cylinder metal is excluded. Also in GOCO cases, costs for DOE oversight of the facility operation and payments in-lieu-of-taxes to local communities are not included.

Annual Expenditure Funding Profile Estimate Basis

The estimated annual expenditures required to support the construction and operation of the DUF6 conversion plant are derived on the basis of the project schedule, and capital and O&M costs estimated in this report. The funding profiles provided are based on a rough macro cost analysis with assumed factors, such as chemical pricing, and, in POPO cases, conversion service payment, interest rates, and loan payment terms. Assumptions and qualifications for the funding profile estimate are as follows:

The conversion plant is assumed operating under either the privately owned and privately operated or government owned and contractor operated scenario.

The conversion plant is designed, constructed, and operated based on the preliminary project schedule developed in this report.

Construction capital cost, start-up and O&M costs, and costs for NEPA/licensing and D&D estimated in this report are used.

The expenditure funding profiles are expressed in fiscal year annually with constant dollar value at first quarter of FY 2000.

For POPO cases, private finance is used to raise the construction capital. The private finance is based on a construction loan with an assumed commercial interest rate to cover the design, construction, and startup expenditures. The loan is paid back during an assumed period after production start with operation revenues from conversion service payment and HF chemical sales. The private operator will receive payment from the government for the conversion service. The payment is based on amount of DUF6 processed after production start at assumed rates such that the private operator's income is near break-even.

HF product is sold to commercial users by the DOE or plant owner at 70¢ per pound based on market quoted price. Revenue from sales is received after production start. CaF2 product is retained by DOE and no revenue is assumed from the product.

Plant amortization deduction, asset depreciation deduction, tax on incomes, and asset salvage after completion of operation and D&D are not considered.